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RELATION OF THE TRANSFORMATION AND DISTRIBUTION OF SOIL NITROGEN TO THE NUTRITION OF CITRUS PLANTS[1]

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INTRODUCTION

The total nitrogen content of Citrus lands is frequently low (1)[2], and it is well recognized that the quantity of available nitrogen formed through the natural processes of nitrification soon becomes inadequate for the needs of Citrus plants unless an effort is made to maintain the nitrogen supply by the addition of commercial fertilizers, cover crops, manure, etc. It has been suggested (7) that the scarcity of organic nitrogen in semiarid soils is offset, to some extent at least, by the great depth to which nitrification takes place in these soils; but, while it is true that nitrification may take place at greater depth in semiarid soils than in humid soils, there seems to be little doubt that the bulk of the nitrates formed in semiarid soils are formed in the surface layers. Few soils are plowed deeper than 9 inches; consequently the cover crops, fertilizers, manure, or other nitrogenous material added are confined to this layer, and the nitrification process naturally is most vigorous in the soil to which nitrogenous organic matter is added from time to time.

In Citrus groves the common practice is to cultivate frequently to a depth of about 6 inches. Comparatively few feeding roots can therefore exist in the upper 6 inches of soil. If the rainfall in southern California was sufficient and was evenly distributed throughout the year, the nitrates formed or carried above the feeding roots by capillarity would be moved downward and brought within reach of the roots at frequent intervals. But the rainfall between April and December is usually too scanty to cause a movement of nitrates from the surface layers of soil; and, as the furrow system of irrigation, which is used most

[1] The work discussed in this paper was carried out in cooperation with the University of California Citrus Experiment Station and Graduate School of Tropical Agriculture at Riverside. The writer wishes to express his indebtedness to Director H. J. Webber and members of his staff for many courtesies and facilities extended during the course of the work.

[2] Reference is made by number to "Literature cited," p. 251–252.

extensively, can not be depended upon to cause a downward movement of the soluble salts from the surface soil, the problem of securing a proper distribution of nitric nitrogen in Citrus soils at once suggests itself.

In many soils a dense plowsole is formed during the irrigation season. The plowsole retards the downward movement of the water, which, under the furrow system, is applied in small streams, several feet apart and several inches below the surface. As the downward movement of the irrigation water is interrupted until the plowsole is softened, which frequently requires several hours, the water moves laterally and upward, not only causing a very uneven distribution of nitrates, but carrying them farther away from the feeding roots. It is therefore obvious that the satisfactory solution of the nitrogen problem in semiarid soils, and especially in furrow-irrigated soils, not only depends upon a knowledge of the factors influencing nitrification, but upon the forces controlling the distribution of nitric nitrogen, which is presumably the most valuable source of nitrogen for crops.

ARRANGEMENT OF EXPERIMENT PLOTS

The major portion of the work presented in this paper has been carried out on the soils of the Citrus Experiment Station grove, at Riverside, Cal.; and it therefore seems desirable to include a brief description of the field and also a diagram (fig. 1) showing the arrangement of plots and the fertilizer applied.

The experimental field was laid out from virgin land in April, 1907. The arrangement of the field is such that each plot is surrounded on all sides by a guard row which effectively prevents the treatment on one plot from influencing the trees on any other. The irrigation of each plot is separate, and no waste water or tailings from one plot is allowed to pass to any other part of the grove.

In planning the experiment a uniform system of fertilization was adopted and each plot has been given the same kind of fertilizer each year, the quantity applied increasing in amount with the development of the trees. During the last four years plots A, C, G, H, L, Q, and S have received each year 1.35 pounds of nitrogen per tree. As there are 108 trees per acre, the applied nitrogen amounts to 145.8 pounds for each acre of land. Plots F and O have received approximately the same quantity of nitrogen in manure until the last year, when the amount applied was in excess of the amount applied to the above-mentioned plots. Plots U and V, which were not originally included in the fertilizer experiment, have received moderate applications of manure in addition to a cover crop of vetch each year. Plots E, K, N, and P have received each year during the last four years about 0.45 pound of nitrogen per tree, or about 48.6 pounds of nitrogen per acre. Plots B, D, I, J, M, R, and T have received no nitrogenous fertilizers at any time.

Plot U
Vetch cover crop, barnyard manure (Pounds): 1914–15 .... 175; 1916 280

Road

Plot A (Pounds) Nitrate of soda........ 4 Blood.............. 2 Potassium sulphate.. 3 Bone............... 14	**Plot F** (Pounds) Manure: 1914–15......... 227 1916............ 350	**Plot K** (Pounds) Bone................ 14 Potassium sulphate.. 3	**Plot P** (Pounds) Bone.............. 14
Plot B No fertilizer.	**Plot G** (Pounds) Nitrate of soda....... 4 Blood.............. 4 Bone............... 14	**Plot L** (Pounds) Nitrate of soda........ 4 Blood............... 5 Potassium sulphate... 3	**Plot Q** (Pounds) Nitrate of soda....... 4 Blood.............. 5 Superphosphate..... 13 Potassium sulphate.. 3
Plot C (Pounds) Blood.............. 10	**Plot H** (Pounds) Nitrate of soda....... 9	**Plot M** No fertilizer.	**Plot R** (Pounds) Potassium sulphate.. 3
Plot D (Pounds) Potassium sulphate.. 3	**Plot I** (Pounds) Muriate of potash... 3	**Plot N** (Pounds) Blood............. 2.5 Superphosphate.... 13.0	**Plot S** (Pounds) Blood............... 10
Plot E (Pounds) Bone............... 14	**Plot J** (Pounds) Superphosphate..... 13	**Plot O** (Pounds) Manure: 1914–15........ 227 1916........... 350 Rock phosphate.... 6	**Plot T** No fertilizer.

Road

Plot V
Vetch cover crop, barnyard manure (Pounds): 1914–15........ 175; 1916.......... 280

Fig. 1.—Diagram of Citrus Experiment Station grove, Riverside, Cal., showing the arrangement of the plots and the kind and quantity of fertilizers applied.

CHANGES IN THE NITROGEN CONTENT OF SOILS FOLLOWING THE ADDITION OF BLOOD OR OTHER ORGANIC SUBSTANCES[1]

In the studies on the changes in the nitrogen content of soils following the addition of nitrogenous materials, a representative sample of soil was secured from each field or plot to be studied by making a large number of borings to a depth of 12 inches. The soil was then thoroughly mixed and passed through a clean sieve to remove gravel, roots, etc., and held in a closed container until the moisture content could be determined. A sufficient quantity of the soil was then weighed out to make 1 kgm. of dry soil, the desired quantity of the substance to be studied was added, thoroughly mixed with the soil, and the moisture content brought up to the optimum. The incubation was carried out in 1-quart Mason jars held at a temperature of 28° C., the optimum moisture content being maintained at all times. When green plants or other substances were added, they were first passed through a grinder which rendered them sufficiently fine to make it possible to secure a uniform distribution in the soil. With the exception of dried blood, the moisture was determined in all materials used, and the addition based on the dry weight.

The ammonia was determined by extracting the soil with 10 per cent hydrochloric acid, rendering an aliquot part of the filtrate alkaline with sodium hydroxid, and then distilling. The reason for using a 10 per cent acid will be discussed at length in a second paper, which will deal especially with the determination of ammonia in semiarid soils. The nitrates were determined by the aluminium-reduction method, which gave very satisfactory results when the reduction was allowed to take place for 24 hours, and an acid trap used to prevent any loss of nitrogen during the reduction period. All determinations were made in duplicate, and, in case there was not a close agreement, additional analyses were made.

The rate at which ammonia and nitrates are formed from green plant material is controlled in a large measure by the maturity of the plants, and in order to secure a fair comparison of different plants it is necessary that they be taken at the same stage of maturity. All plants used in the following experiment were therefore selected at the flowering stage, unless otherwise stated in the text.

The total nitrogen determinations were all made in triplicate by the Kjeldahl-Gunning-Jodblauer process.

On April 8, 1914, soil samples were taken from three plots in the Citrus Experiment Station grove and the transformation of nitrogen, following the addition of blood or other nitrifiable materials, studied. The ammonia and nitrates were determined at 7-day intervals for a period of 6 weeks. At the end of the incubation period the total nitrogen was determined, and the gain or loss of nitrogen during the incubation period calculated from the original nitrogen content of the soil and the nitrogen added in the dried blood or plant substances.

[1] In all ammonification or nitrification studies in which dried blood or other nitrogenous materials were used, the figures given represent the gain in ammonia or nitrates over the amount found in the control samples which received water only.

TABLE I.—*Nitrification of dried blood, barley hay, horse manure, and green manures in Citrus Experiment Station soils, Riverside, Cal. April 8, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

PLOT E

Material added.	Constituent.	Incubation period.					
		7 days.	14 days.	21 days.	28 days.	35 days.	42 days.
Dried blood (1 per cent)	Ammonia	35.28	33.20	25.66	25.48	25.76	25.48
Do.	Nitrates	3.04	30.94	47.31	46.37	49.61	47.29
Oats (1 per cent)	Ammonia	.56	1.28	1.12	−.28	.46	.84
Do.	Nitrates	.09	.57	.74	.46	.38	.33
Barley (1 per cent)	Ammonia	.56	.16	−.09	−.28	.00	.21
Do.	Nitrates	.51	.42	.53	−.03	2.57	1.38
Melilotus (1 per cent)	Ammonia	2.24	.72	.56	1.40	1.68	1.40
Do.	Nitrates	3.65	5.23	8.70	11.40	10.22	8.73
Alfilaria (1 per cent)	Ammonia	1.12	.16	.14	.28	.68	.28
Do.	Nitrates	.73	.84	.98	1.28	1.32	2.02
Water only	Ammonia	1.12	.96	1.12	1.40	1.12	.84
Do.	Nitrates	.96	1.40	1.68	2.40	2.24	2.80
PLOT D							
Dried blood (1 per cent)	Ammonia	47.92	54.24	58.44	46.36	47.96	45.02
Do	Nitrates	.99	−1.40	−.99	6.27	13.69	15.75
Oats (1 per cent)	Ammonia	.00	.56	.00	.44	.00	.28
Do.	Nitrates	.01	−1.77	−.01	1.21	1.57	2.83
Barley (1 per cent)	Ammonia	.00	1.12	.56	.58	.56	.44
Do.	Nitrates	1.48	−1.77	−.77	2.81	3.45	3.83
Melilotus (1 per cent)	Ammonia	1.68	1.68	.00	.00	.00	.00
Do.	Nitrates	2.07	2.58	3.06	5.90	6.01	7.77
Alfilaria (1 per cent)	Ammonia	.56	.56	.00	.44	.56	.40
Do.	Nitrates	1.81	.33	1.01	2.85	2.87	3.45
Water only	Ammonia	1.68	1.12	1.12	1.24	1.12	.96
Do.	Nitrates	1.25	3.54	3.09	1.95	2.22	2.18
PLOT C							
Dried blood (1 per cent)	Ammonia	33.44	34.72	31.36	24.64	25.20	24.08
Do.	Nitrates	3.10	7.39	15.31	17.46	28.99	29.41
Barley hay (1 per cent)	Ammonia	−.16	−.44	.00	.00	.00	.00
Do.	Nitrates	−1.31	−1.18	−.66	−.72	−.63	−.42
Barley (1 per cent)	Ammonia	.40	.80	.00	.56	.55	.00
Do.	Nitrates	1.56	3.73	3.98	3.28	2.89	2.37
Melilotus (1 per cent)	Ammonia	1.96	.56	.00	−.42	.00	.00
Do.	Nitrates	2.62	3.00	3.76	7.29	7.39	8.37
Horse manure (1 per cent)	Ammonia	.00	−.56	.00	.00	.00	.00
Do.	Nitrates	−.42	.45	−.66	.86	1.07	1.29
Water only	Ammonia	1.84	1.68	1.68	1.68	1.12	1.12
Do.	Nitrates	1.73	1.70	2.65	2.88	2.36	2.83

In studying the figures presented in Table I it is seen that the increase in ammonia resulting from the application of 1 per cent of blood reaches the maximum in soil E after 7 days, in soil C after 14 days, and in soil D not until after 21 days. It is observed that the ammonia is uniformly higher in soil D than in soil E or C. Some increase in nitrates is observed

in all of the soils after the first 7 days, and in soil C the amount increases somewhat uniformly until the end of the experiment. In soil E a rapid increase in nitrates is noted from 7 to 21 days; but during the last 3 weeks the gain is irregular and very slow. In soil D a loss of nitrates occurs between 7 to 21 days. It is interesting to note that during this period the ammonia is very high, and there is a possibility of the action of the nitrifying organism being inhibited by the presence of so much ammonia.

By referring to Table II it is seen that the percentage of nitrogen recovered as ammonia varies from 17.55 in soil C to 32.81 in soil D, while the percentage of the nitrogen recovered as nitrates varies from 11.48 in soil D to 34.47 in soil E. The average loss of nitrogen from the three soils following the addition of 1 per cent of blood is 29.25 per cent of the nitrogen added.

TABLE II.—*Percentage of nitrogen added to soils in dried blood, barley hay, horse manure, and green manures recovered as ammonia and nitrates after six weeks' incubation; also percentage gain or loss of nitrogen added. April 8, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Material added	Nitrogen in material added.	Nitrogen as ammonia recovered in 6 weeks.	Percentage of nitrogen as ammonia recovered.	Nitrogen as nitrate recovered in 6 weeks.	Percentage of nitrogen as nitrate recovered.	Nitrogen remaining in soil after 6 weeks.	Gain or loss.	Percentage of nitrogen gained or lost.
PLOT E								
Dried blood (1 per cent).......	137.20	25.48	18.57	47.29	34.47	92.80	−44.40	−32.36
Oats, green (1 per cent).......	16.90	.84	4.97	.33	1.95	33.00	16.10	95.27
Barley, green (1 per cent).....	14.20	.21	1.48	1.38	9.72	24.50	10.30	72.53
Melilotus, green (1 per cent)..	21.20	1.40	6.60	8.73	41.18	34.00	12.80	60.38
Alfilaria, green (1 per cent)...	18.80	.28	1.49	2.02	10.74	26.60	7.80	41.49
PLOT D								
Dried blood (1 per cent).......	137.20	45.02	32.81	15.75	11.48	95.20	42.00	−30.61
Oats, green (1 per cent).......	16.90	.28	1.66	2.83	16.74	29.20	12.30	72.78
Barley, green (1 per cent).....	14.20	.44	3.10	3.83	26.97	28.10	13.90	97.89
Melilotus, green (1 per cent)....	21.20	.00	.00	7.77	36.65	35.30	14.10	66.51
Alfilaria, green (1 per cent).....	18.80	.40	2.13	3.45	18.35	28.00	9.20	48.94
PLOT C								
Dried blood (1 per cent........	137.20	24.08	17.55	29.41	21.44	103.20	−34.00	−24.78
Barley hay (1 per cent)........	13.60	.00	.00	−.42	−3.09	16.10	2.50	18.38
Barley, green (1 per cent).....	14.20	.00	.00	2.37	16.69	19.60	5.40	38.03
Melilotus, green (1 per cent)...	21.20	.00	.00	8.39	39.58	31.40	10.20	48.11
Horse manure (1 per cent).....	13.60	.00	.00	1.29	9.49	21.00	7.40	54.41

The addition of 1 per cent of oats caused a moderate increase in ammonia in soil E, but very little increase in soil D. However, after 42 days' incubation the ammonia content of both soils was somewhat higher than in the controls. It would seem that very little increase in nitrates resulted from the addition of the oats to soil E, and the increase in soil D amounts to only 2.83 mgm. The percentage of nitrogen recovered as ammonia was 4.97 in soil E and 1.66 in soil D. The percentage of

nitrogen recovered as nitrates in soil E was only 1.95, but in soil D the percentage recovered as nitrates amounted to 16.74. Both of the soils to which oats were added show gains in total nitrogen, amounting to 95.27 per cent of the nitrogen added in soil E and 72.78 per cent in soil D.

The addition of 1 per cent of green barley caused only slight increases in ammonia, and the increase in nitrates after 6 weeks' incubation varied from 1.38 mgm. in soil E to 3.83 mgm. in soil D.

One per cent of melilotus caused a decided gain in ammonia in all soils during the early part of the incubation period, and in soil E the increase in ammonia caused by the decay of the melilotus is apparent throughout the experiment, but after 21 days soils D and C contained no more ammonia than the controls.

The increase in nitric nitrogen resulting from the addition of green melilotus begins during the first few days. After seven-days' incubation the average gain for the three soils is more than the average gain from oats or barley during the entire six weeks' incubation. In soil E the maximum increase in nitrates is obtained after 28 days. In soils D and C the gain continues throughout the six weeks; but the total increase is less than in the soil in which the maximum gain is attained in a shorter period.

None of the nitrogen added in melilotus in soils C and D remained in the soil as ammonia, but 6.6 per cent remained in soil E. Nearly 40 per cent of the nitrogen added in melilotus was recovered as nitrates and the nitrogen gains in the three soils varied from 48.11 per cent of the nitrogen added in soil C to 66.51 per cent in soil D.

The addition of 1 per cent of alfilaria showed an increase in ammonia after seven days, but after the seven-day period the increase over the controls was very small. Small gains in nitrates were secured in seven days, and the increase proceeded gradually during the six weeks' incubation.

A little less than 2 per cent of the nitrogen added in alfilaria was recovered as ammonia, and from 10.74 to 18.35 per cent as nitrates. The nitrogen gain from alfilaria is smaller than from oats, barley, or melilotus.

The addition of barley hay showed no increase in ammonia at any time during the experiment. Neither was there any increase in nitrates in this soil over the supply in the control, thus indicating that the nitrification of mature barley is much slower than the nitrification of green manures.

Horse manure was used only in soil C, in which it caused no apparent increase in ammonia over the control. Nitrification proceeded slowly and somewhat irregularly. The gain in nitrates over the control amounts to only 1.29 mgm. in six weeks. Only 9.49 per cent of the nitrogen added in horse manure was recovered as nitrates. However, there was a gain in nitrogen amounting to 54.41 per cent of the nitrogen added.

The ammonia content of the control soils remained rather constant throughout the experiment, but the nitric nitrogen increased slowly and somewhat irregularly. At the conclusion of the experiment, the average nitrate content in the three soils amounts to 2.61 mgm. per 100 gm. of soil, which would be approximately 100 pounds of nitrogen per acre-foot of soil. This rate of nitrification would seem to be sufficient to supply the needs of any crop. However, if these soils had remained in the field undisturbed except by the ordinary cultivation, it is doubtful whether the increase in nitrates would have amounted to more than a fraction of the gains secured under laboratory conditions.

On June 23, 1914, three soil samples were secured from Highland, Cal. One sample was taken from a productive grove, one from an unproductive grove, and a third from an adjacent virgin soil. The nitrogen changes in these soils following the addition of blood, red clover, or alfalfa are shown in Tables III and IV.

TABLE III.—*Nitrification of dried blood and green manures in soils from Highland, Cal. June 23, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Material added.	Constituent.	Incubation period.					
		7 days.	14 days.	21 days.	28 days.	35 days.	42 days.
PRODUCTIVE SOIL							
Dried blood (1 per cent).	Ammonia..	29.12	38.36	33.04	36.40	32.76	32.20
Red clover (1 per cent)..	Nitrates....	.56	2.80	10.08	9.84	8.96	8.96
Do.	Ammonia..	−.00	−.56	.28	−.28	.28	.00
Do.	Nitrates....	.84	3.48	5.90	7.64	9.52	11.48
Alfalfa (1 per cent).	Ammonia..	1.68	−.28	1.12	.00	.56	.56
Do.	Nitrates....	3.92	10.08	13.44	14.84	16.24	15.96
Water only.	Ammonia..	1.68	1.96	1.12	1.40	1.12	1.12
Do.	Nitrates....	1.40	1.40	2.24	1.96	2.24	1.96
UNPRODUCTIVE SOIL							
Dried blood (1 per cent..	Ammonia..	32.20	38.40	38.08	34.88	34.16	33.88
Do.	Nitrates....	.28	.28	4.20	5.00	7.00	8.96
Red clover (1 per cent)..	Ammonia..	−.28	−.28	.00	.24	.00	.00
Do.	Nitrates....	1.12	2.25	2.24	3.80	5.60	7.00
Alfalfa (1 per cent).	Ammonia..	4.20	2.24	.28	.74	.84	.84
Do.	Nitrates....	7.28	15.40	14.84	17.26	18.20	18.76
Water only.	Ammonia..	1.68	1.40	1.40	1.12	1.40	1.12
Do.	Nitrates....	1.12	1.40	1.68	1.80	1.96	1.68
VIRGIN SOIL							
Dried blood (1 per cent)..	Ammonia..	21.28	26.32	29.40	37.86	29.48	28.00
Do.	Nitrates....	1.12	8.68	20.20	18.76	19.92	19.04
Red clover (1 per cent)..	Ammonia..	−.28	.28	.24	.42	.14	.28
Do.	Nitrates....	.28	1.68	3.08	7.28	7.96	11.48
Alfalfa (1 per cent).	Ammonia..	−.28	.28	.28	.14	.28	.00
Do.	Nitrates....	.84	3.92	8.40	10.08	12.52	13.72
Water only.	Ammonia..	1.40	1.12	1.12	.98	1.12	1.12
Do.	Nitrates....	1.12	1.40	1.68	1.40	1.68	1.40

TABLE IV.—*Percentage of nitrogen added to Highland, Cal., soils in dried blood and green manures recovered as ammonia and nitrates after six weeks' incubation; also percentage gain or loss of nitrogen added. June 23, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Material added.	Nitrogen in material added.	Nitrogen as ammonia recovered in 6 weeks.	Percentage of nitrogen as ammonia recovered.	Nitrogen as nitrate recovered in 6 weeks.	Percentage of nitrogen as nitrate recovered.	Nitrogen remaining in soil after 6 weeks.	Gain or loss in nitrogen.	Percentage of nitrogen gained or lost.
PRODUCTIVE SOIL								
Dried blood (1 per cent).......	137.20	32.00	23.32	8.96	6.53	62.90	−74.30	−54.15
Red clover (1 per cent)........	20.07	.00	.00	11.48	57.20	30.70	10.63	52.96
Alfalfa (1 per cent)............	28.60	.56	1.96	15.96	55.81	39.10	10.50	36.71
UNPRODUCTIVE SOIL								
Dried blood (1 per cent).......	137.20	33.88	24.69	8.96	6.53	67.50	−69.70	−50.80
Red clover (1 per cent)........	20.07	.00	.00	7.00	34.88	26.90	6.83	34.03
Alfalfa (1 per cent)............	28.60	.84	2.94	18.76	65.59	38.10	9.50	33.20
VIRGIN SOIL								
Dried blood (1 per cent).......	137.20	28.00	20.41	19.04	13.88	66.00	−71.20	−51.89
Red clover (1 per cent)........	20.07	.28	1.37	11.48	57.20	25.00	4.93	24.56
Alfalfa (1 per cent)............	28.60	.00	.00	13.72	47.97	35.00	6.40	22.38

The addition of 1 per cent of dried blood to these soils caused a rapid increase in the ammonia content. At the end of the first seven days the ammonia in these three soils varied from 21.28 to 32.2 mgm. per 100 gm. of soil, and there was little tendency for the ammonia to decrease during the latter part of the incubation period. The percentage of nitrogen recovered as ammonia, as shown in Table IV, varied from 20.41 in the virgin soil to 24.69 in the unproductive soil. The increase in nitric nitrogen following the addition of 1 per cent of dried blood was rather low in these soils. In the productive soil and also in the virgin soil the maximum increase in nitrates was secured after 21 days. In the unproductive soil there was a slow but steady increase in nitrates throughout the incubation period. The percentage of nitrogen recovered as nitrates is in all cases less than the percentage recovered as ammonia. The loss of nitrogen was very heavy in all of these soils, the average for the three soils being above 50 per cent of the nitrogen added.

When 1 per cent of red clover was added, there was a reduction in the ammonia content of the virgin and unproductive soils during the first seven days and no increase in the productive soil. At no time during the incubation period of six weeks did the increase in ammonia amount to more than 0.42 mgm. per 100 gm. of soil. At the conclusion of the experiment, none of the nitrogen added in red clover was recovered as ammonia in the productive or unproductive soils and only 1.37 per cent in the virgin soil. The increase in nitric nitrogen from the addition of

red clover began during the first seven days and continued to increase rather uniformly throughout the experiment. At the conclusion of the experiment, from 34.88 to 57.2 per cent of the nitrogen added was recovered as nitrates. The increase in total nitrogen in the soils receiving red clover varied from 24.56 per cent in the virgin soil to 52.96 per cent in the productive soil.

The addition of 1 per cent of alfalfa caused considerable increase in the ammonia content of the productive and unproductive soils during the first seven days, but a slight reduction in the virgin soil. During the latter part of the incubation period the increase in ammonia in these soils is very small, and the percentage of nitrogen recovered as ammonia at the conclusion of the experiment varied from nothing in the virgin soil to 2.94 in the unproductive soil. Considerable increase in nitric nitrogen took place during the first seven days in the productive and unproductive soils, but very little increase in the virgin soil. The nitric nitrogen continued to increase throughout the incubation period, and at the end of the six weeks the percentage of nitrogen recovered as nitrates from alfalfa varied from 47.97 in the virgin soil to 65.59 in the unproductive soil. There was a gain in total nitrogen in each of the soils to which alfalfa was added.

When these soils were incubated without the addition of nitrogenous materials, the ammonia content remained quite uniform throughout the incubation period; but there was an appreciable increase in nitrates, which seemed to have reached a maximum after 21 days in the productive and virgin soil and after 35 days in the unproductive soil.

On July 16, soil samples were secured from four plots in the experimental field at the Citrus Experiment Station, Riverside, Cal., and one sample from an adjacent virgin soil. Each of these soils was divided into four portions of 1 kgm. each, one portion from each soil receiving 1 per cent of dried blood. Each of the other portions received 2 per cent of red clover, alfalfa, or buckwheat. The results obtained in this experiment are presented in Table V.

When 1 per cent of dried blood was added to these soils, there was a considerable increase in the ammonia content of each of the five soils included in the experiment. The percentage of nitrogen recovered as ammonia at the end of six weeks varied from 18.25 in soil U to 38.37 in the virgin soil. The increase in nitric nitrogen in these soils is extremely variable. In the virgin soil and soil B only 1.22 per cent of the nitrogen added in dried blood was recovered as nitrates, while in soils F and U 32.65 and 36 per cent, respectively, were recovered. The percentage of nitrogen lost varied from 13.05 in plot F to 47.96 in plot B.

When 2 per cent of red clover was added, there was an appreciable increase in the ammonia content of all of the soils. However, the average percentage of nitrogen recovered as ammonia is only 4.5. The lowest increase in nitrates is in the virgin soil and amounts to 26.51 per cent

of the nitrogen added. With the exception of soil B, there is an increase in total nitrogen following the addition of the clover, which in soil U amounts to 32.54 per cent of the nitrogen added.

TABLE V.—*Percentage of nitrogen added to soils in dried blood and green manures recovered as ammonia and nitrates after six weeks' incubation; also percentage gain or loss of nitrogen added. July 16, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Materials added.	Nitrogen in material added.	Nitrogen as ammonia recovered in 6 weeks.	Percentage of nitrogen as ammonia recovered.	Nitrogen as nitrate recovered in 6 weeks.	Percentage of nitrogen as nitrate recovered.	Nitrogen remaining in soil after 6 weeks.	Gain or loss in nitrogen.	Percentage of nitrogen gained or lost.
PLOT U								
Dried blood (1 per cent)	137.20	25.04	18.25	49.40	36.00	108.60	−28.60	−20.85
Red clover (2 per cent)	40.14	1.96	4.88	14.56	36.27	53.20	13.06	32.54
Alfalfa (2 per cent)	57.20	2.24	3.92	17.64	30.84	75.60	18.40	32.17
Buckwheat (2 per cent)	33.12	1.40	4.23	8.12	24.52	35.00	1.88	5.68
PLOT F								
Dried blood (1 per cent)	137.20	33.04	24.08	44.80	32.65	119.30	−17.90	−13.05
Red clover (2 per cent)	40.14	1.40	3.49	16.24	40.46	50.69	10.55	26.28
Alfalfa (2 per cent)	57.20	1.68	2.94	19.04	33.29	70.50	13.30	23.25
Buckwheat (2 per cent)	33.12	.84	2.54	2.52	7.61	33.90	.78	2.36
PLOT B								
Dried blood (1 per cent)	137.20	50.68	36.94	1.68	1.22	71.40	−65.80	−47.96
Red clover (2 per cent)	40.14	2.24	5.59	12.04	30.00	40.14	.00	.00
Alfalfa (2 per cent)	57.20	2.24	3.92	14.00	24.48	51.80	− 5.40	− 9.44
Buckwheat (2 per cent)	33.12	1.68	5.07	1.12	3.38	25.22	− 7.90	−23.85
PLOT H								
Dried blood (1 per cent)	137.20	51.40	37.46	5.76	4.20	98.70	−38.50	−26.06
Red clover (2 per cent)	40.14	1.68	4.19	12.88	32.09	44.10	3.96	9.87
Alfalfa (2 per cent)	57.20	2.24	3.92	15.12	26.43	53.90	− 3.30	− 5.77
Buckwheat (2 per cent)	33.12	1.12	3.38	1.40	4.23	23.10	−10.02	−30.25
VIRGIN SOIL								
Dried blood (1 per cent)	137.20	52.64	38.37	1.68	1.22	81.20	−56.00	−40.80
Red clover (2 per cent)	40.14	1.68	4.19	10.64	26.51	49.00	8.86	22.07
Alfalfa (2 per cent)	57.20	1.68	2.94	14.56	25.46	61.60	4.40	7.69
Buckwheat (2 per cent)	33.12	1.12	3.38	1.12	3.38	32.20	− .92	− 2.78

The addition of 2 per cent of alfalfa caused only a small increase in the ammonia content of the soil, but a marked gain in nitric nitrogen, from 24.48 to 33.29 per cent of the nitrogen in the alfalfa being converted into nitrates. Considerable gains in total nitrogen were secured in soils U and F and a small gain in the virgin soil, but soils B and H showed a small loss of nitrogen.

Buckwheat caused a somewhat smaller increase in the ammonia content of the soil than did red clover or alfalfa. The percentage of nitrogen recovered from buckwheat as nitrates is very much smaller than the

percentage recovered from red clover or alfalfa. Small nitrogen gains were secured from buckwheat in soils U and F, but in soils B and H there was considerable nitrogen lost and a small loss in the virgin soil.

On August 28 a third set of samples was taken from the experimental plots at Riverside and one sample from the adjacent virgin soil. Each sample was divided into nine portions. One portion of each soil was conducted as a control. The other portions received, respectively, 1 per cent of dried blood, 2 per cent of vetch, melilotus, soybeans, corn, cowpeas, black-eyed peas, or oats. The results obtained in this experiment are presented in Tables VI and VII.

TABLE VI.—*Nitrification of dried blood and green manures in Citrus Experiment Station soils, Riverside, Cal. August 28, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Material added.	Constituent.	Plot U.			Plot H.			Plot B.		
		Incubation period.			Incubation period.			Incubation period.		
		14 days.	28 days.	42 days.	14 days.	28 days.	42 days.	14 days.	28 days.	42 days.
Dried blood (1 per cent)	Ammonia.	4.34	6.72	6.44	34.44	43.40	32.48	35.56	45.92	47.74
Do	Nitrates	42.28	66.36	70.56	.56	.34	.00	.28	3.92	−.42
Vetch (2 per cent)	Ammonia.	4.34	1.68	1.68	10.92	9.52	8.12	8.68	17.92	13.58
Do	Nitrates	17.08	24.92	26.32	5.60	12.10	11.48	.56	6.02	14.42
Melilotus (2 per cent)	Ammonia.	1.82	1.96	1.40	8.96	4.76	.70	9.80	4.76	1.70
Do	Nitrates	14.84	30.24	34.16	5.04	12.99	13.72	2.80	15.12	15.60
Soybeans (2 per cent)	Ammonia.	.14	.00	−.14	.00	.00	.00	.00	1.68	.26
Do	Nitrates	2.12	7.28	12.04	2.80	9.02	10.64	1.68	7.84	21.34
Corn (2 per cent)	Ammonia.	.14	.00	.00	.00	.28	.00	.28	.84	1.18
Do	Nitrates	.28	9.24	18.20	.28	4.54	14.84	.84	1.96	17.00
Cowpeas (2 per cent)	Ammonia.	.30	.28	.00	−.14	.00	.00	.14	1.40	.70
Do	Nitrates	−.70	1.12	22.04	−.56	10.98	12.32	.00	6.72	12.48
Black-eyed peas (2 per cent).	Ammonia.	4.34	1.68	.98	2.80	1.68	.56	5.60	1.68	1.26
Do	Nitrates	−.56	10.36	18.96	−.56	15.18	12.88	.14	2.08	15.54
Oats (2 per cent)	Ammonia.	.00	.00	−.28	.00	.28	.00	−.42	.28	.26
Do	Nitrates	−.69	−1.40	−1.68	−.56	−.34	−2.16	.28	−.84	−.84
Water only	Ammonia.	.98	1.40	1.40	1.12	1.40	1.12	.84	1.12	.98
Do	Nitrates	1.12	1.96	2.26	1.12	1.90	2.80	.56	1.40	1.26

Material added.	Constituent.	Plot F.			Virgin soil.		
		Incubation period.			Incubation period.		
		14 days.	28 days.	42 days.	14 days.	28 days.	42 days.
Dried blood (1 per cent)	Ammonia	24.64	28.14	27.16	36.42	51.44	41.28
Do	Nitrates	11.64	44.24	50.68	−.14	−.28	−.56
Vetch (2 per cent)	Ammonia	5.88	.72	.39	.30	14.98	7.20
Do	Nitrates	8.56	15.40	19.32	.14	−.14	−.84
Melilotus (2 per cent)	Ammonia	.44	1.54	.74	10.50	17.78	11.60
Do	Nitrates	14.12	38.30	40.88	.00	3.64	13.16
Soybeans (2 per cent)	Ammonia	−.16	.32	.28	.00	.14	.40
Do	Nitrates	2.34	9.80	13.44	.00	3.12	7.12
Corn (2 per cent)	Ammonia	−.14	.70	.70	3.22	1.26	.34
Do	Nitrates	.02	10.92	18.72	.00	8.68	14.84
Cowpeas (2 per cent)	Ammonia	−.28	.22	.28	.28	1.82	.54
Do	Nitrates	−.40	6.16	22.68	−.14	.84	10.08
Black-eyed peas (2 per cent)	Ammonia	4.52	1.54	1.68	5.18	10.50	3.20
Do	Nitrates	−.12	13.72	19.84	−.14	3.92	12.88
Oats (2 per cent)	Ammonia	−.28	.14	−.14	−.14	.14	−.72
Do	Nitrates	−.40	−.84	−1.40	−.28	−.56	−1.26
Water only	Ammonia	1.12	1.26	1.12	.98	1.82	1.28
Do	Nitrates	.96	1.68	1.96	.70	1.12	1.68

TABLE VII.—*Percentage of nitrogen added to soils in dried blood and green manures recovered as ammonia and nitrates after six weeks' incubation; also percentage gain or loss of nitrogen added. August 28, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Material added.	Nitrogen in material added.	Nitrogen as ammonia recovered in 6 weeks.	Percentage of nitrogen as ammonia recovered.	Nitrogen as nitrate recovered in 6 weeks.	Percentage of nitrogen as nitrate recovered.	Nitrogen remaining in soil after 6 weeks.	Gain or loss in nitrogen	Percentage of nitrogen gained or lost.
PLOT U								
Dried blood (1 per cent)	137.20	6.44	4.69	70.56	51.43	119.00	−18.20	−13.27
Vetch 2 (per cent)	65.20	1.68	2.58	26.32	40.37	77.00	11.80	18.10
Melilotus (2 per cent)	48.40	1.40	2.89	34.16	70.58	86.60	38.20	78.93
Soybeans (2 per cent)	43.40	− .14	.32	12.04	27.74	49.00	5.60	1.29
Corn (2 per cent)	30.02	.00	.00	18.20	60.61	69.30	39.26	130.20
Cowpeas (2 per cent)	45.00	.00	.00	22.04	48.98	63.70	18.70	41.56
Black-eyed peas (2 per cent)	42.40	.98	2.31	18.96	44.72	72.10	19.70	70.05
Oats (2 per cent)	20.20	− .28	−1.39	−1.68	−8.32	21.70	1.50	7.43
PLOT H								
Dried blood (1 per cent)	137.20	32.48	23.67	0.00	0.00	57.40	−79.80	−58.16
Vetch (2 per cent)	65.20	8.12	12.45	11.48	17.61	64.40	− .80	−1.23
Melilotus (2 per cent)	48.40	.70	1.45	13.72	28.35	79.80	31.40	64.88
Soybeans (2 per cent)	43.40	.00	.00	10.64	24.52	44.80	1.40	3.23
Corn (2 per cent)	30.02	.00	.00	14.84	49.43	75.60	45.58	151.90
Cowpeas (2 per cent)	45.00	.00	.00	12.32	27.38	58.80	13.80	30.66
Black-eyed peas (2 per cent)	42.40	.56	1.33	12.88	30.38	63.00	20.60	48.58
Oats (2 per cent)	20.20	.00	.00	−2.16	−10.69	19.60	− .60	−2.97
PLOT B								
Dried blood (1 per per cent)	137.20	47.74	34.79	0.00	0.00	63.00	−74.20	−54.08
Vetch (2 per cent)	65.20	13.58	20.83	14.42	22.11	71.40	6.20	9.51
Melilotus (2 per cent)	48.40	1.70	3.51	15.60	32.23	74.90	26.50	54.75
Soybeans (2 per cent)	43.40	.26	.60	11.34	26.13	46.20	2.80	6.45
Corn (2 per cent)	30.02	1.18	3.93	17.00	56.63	72.10	42.08	140.17
Cowpeas (2 per cent)	45.00	.70	1.56	12.48	27.73	51.80	6.80	15.11
Black-eyed peas (2 per cent)	42.40	1.26	2.96	15.54	36.65	50.40	8.00	18.87
Oats (2 per cent)	20.20	.26	1.29	−.84	−4.16	16.80	− 3.40	−16.83
PLOT F								
Dried blood (1 per cent ..)	137.20	27.16	19.79	50.68	36.94	112.00	−25.20	− 18.37
Vetch (2 per cent)	65.20	10.39	.60	19.32	29.63	74.20	9.00	13.80
Melilotus (2 per cent)	48.40	.74	1.53	40.88	84.46	99.40	51.00	105.37
Soybeans (2 per cent)	43.40	.28	.65	13.44	30.97	51.80	8.40	19.36
Corn (2 per cent)	30.02	.70	2.33	18.72	62.36	70.70	40.68	135.51
Cowpeas (2 per cent)	45.00	.28	.62	22.68	50.40	65.80	20.80	46.22
Black-eyed peas (2 per cent)	42.40	1.68	3.96	19.84	46.79	76.30	33.90	79.95
Oats (2 per cent)	20.20	− .14	− .69	−1.40	− 7.23	22.50	2.30	11.39
VIRGIN SOIL								
Dried blood (1 per cent)	137.20	41.28	30.09	− 0.56	− 0.41	70.00	−67.20	− 48.48
Vetch (2 per cent)	65.20	7.20	11.04	− .84	− 1.29	65.00	− .20	− .31
Melilotus (2 per cent)	48.40	11.60	23.97	13.16	27.19	74.20	25.80	53.31
Soybeans (2 per cent)	43.40	.40	.92	7.12	16.41	45.20	1.80	4.15
Corn (2 per cent)	30.02	.34	1.13	14.84	49.43	67.20	37.18	123.85
Cowpeas (2 per cent)	45.00	.54	1.20	10.08	24.00	63.20	18.20	40.44
Black-eyed peas (2 per cent)	42.40	3.20	7.55	12.88	30.38	57.40	15.00	35.38
Oats (2 per cent)	20.20	− .72	− 3.56	− 1.26	− 6.24	19.16	− 1.04	− 5.15

It is seen that the addition of 1 per cent of dried blood caused a large increase in the ammonia content of soils H, B, and virgin, a smaller increase in soil F, and a comparatively small increase in soil U. The percentage of nitrogen recovered as ammonia from the dried blood varies from 4.69 in soil U to 34.79 in soil B. There was no increase in nitric nitrogen in the virgin soil at any time during the incubation period of six weeks. On the other hand, the results indicate that there was a slight reduction of nitrates as compared with the amount found in the control. The increase in nitric nitrogen in soils H and B is very little; but in soils F and U there is a decided increase after the first 14 days, and the increase continues throughout the incubation period. In soil U 51.43 per cent of the nitrogen added in dried blood was recovered as nitrates after six weeks' incubation. In soils H, B, and virgin none of the nitrogen added as dried blood was recovered as nitrates. The loss of nitrogen from the addition of 1 per cent of dried blood varies from 13.27 per cent in soil U to 58.16 per cent in soil H.

The addition of 2 per cent of vetch caused an increase in the ammonia content of all of the soils, but the amount of increase is small as compared with the increase from dried blood. At the conclusion of the experiment the percentage of nitrogen recovered as ammonia varied from 2.58 in soil U to 20.83 in soil B. After 14 days there was an increase in nitrates in all of the soils to which vetch had been added, but the increase in the virgin soil and soil B were very small, and during the latter part of the incubation period the virgin soil, to which 2 per cent of vetch had been added, contained less nitric nitrogen than the control. In soil U 40.37 per cent of the nitrogen added in vetch was recovered as nitrates after six weeks' incubation, the virgin being the only soil in the series which failed to give less than 17.61 per cent of nitrogen as nitrates. Soil H and the virgin soil show a slight loss of total nitrogen, while soils F, B, and U show slight gains, varying from 9.51 to 18.1 per cent of the nitrogen added.

The addition of melilotus caused only a small increase in the ammonia in soils U and F, but considerable increases in soils H and B and the virgin soil. At the conclusion of the experiment the ammonia recovered from melilotus varied from 1.45 per cent in soil H to 23.97 per cent in the virgin soil. After 14 days' incubation soils U and F showed a marked increase in nitrates, soils H and B comparatively small increases, while the virgin soil showed no increase. There are gains in nitrates in all of the soils of from 14 to 42 days, and at the conclusion of the experiment the percentage of nitrogen recovered as nitrates from melilotus varies from 27.19 in the virgin soil to 84.46 in soil F. There is a decided increase in the total nitrogen in all of the soils receiving melilotus. In soil F the increase amounts to more than the nitrogen added in melilotus.

Soybeans, unlike vetch or melilotus, caused very little or no increase in the ammonia content of the soils. The increase in nitrates is also

slower than when vetch or melilotus was added. The highest percentage of nitrogen as nitrates recovered from soybeans was 30.97. The increase in total nitrogen is also comparatively low.

The addition of 2 per cent of corn gave very little or no increase in the ammonia content, and the increase in nitrates after the first 14 days was very small, and in some instances no increase was found. However, during the latter part of the incubation period the formation of nitrates took place more rapidly, and at the conclusion of the experiment 62.36 per cent of the nitrogen added in corn was recovered as nitrates in soil F, the average for the five soils being well above 50 per cent. The percentage increase in nitrogen varies from 123.3 in the virgin soil to 151.9 in soil H.

The addition of cowpeas, like the addition of soybeans and corn, caused very little or no increase in ammonia. Nitrification appears to have started somewhat slowly; but, when once started, the increase continued rather rapidly until the end of the experiment. In all of the soils the percentage of nitrogen recovered from soybeans as nitrates varies from 24 in the virgin soil to 50.4 in soil F. All of the soils show an increase in total nitrogen, although the increase is much smaller than that received from the addition of corn.

Black-eyed peas caused a moderate increase in ammonia in all of the soils. At the conclusion of the experiment the percentage of nitrogen recovered from black-eyed peas as ammonia varied from 1.33 in soil H to 7.55 in the virgin soil. There appears to have been a slight loss in nitrates at the end of 14 days in all of the soils except soil B, in which the increase amounted to only 0.14 mgm. During the latter part of the incubation period considerable quantities of nitrates were formed from black-eyed peas, and at the conclusion of the experiment the percentage of the nitrogen recovered as nitrates varied from 30.38 per cent in the virgin soil to 46.79 per cent in soil F. There was an increase in the total nitrogen in all of the soil, which varied from 18.87 per cent in soil B to 79.95 per cent in soil F.

The addition of 2 per cent of oats caused very little or no increase in the ammonia content of the soils; neither was there any increase in nitrates; but, on the other hand, the addition of oats seems to have reduced somewhat the nitrate content of all of the soils. There were small gains in total nitrogen in soils U and F, but small losses in H, B, and the virgin soils.

In the control samples the ammonia remained fairly constant throughout the experiment, but there was a slow and quite uniform increase in nitrates.

A fourth series of samples was taken from the experimental plots at Riverside on November 4, 1914, and handled similarly to those taken on August 28, except that the green manures added were generally different. The results secured in this experiment are given in Tables VIII and IX.

TABLE VIII.—*Nitrification of dried blood and green manures in Citrus Experiment Station soils, Riverside, Cal. November 4, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Material added.	Constituent.	Plot U. Incubation period.			Plot F. Incubation period.			Plot H. Incubation period.		
		14 days.	28 days.	42 days.	14 days.	28 days.	42 days.	14 days.	28 days.	42 days.
Dried blood (1 per cent).	Ammonia.	17.22	18.34	16.66	43.54	47.74	28.98	47.88	49.70	40.88
Do.	Nitrates.	30.24	37.35	49.56	− .40	.00	2.94	− .84	− 3.22	− 1.68
Sweet corn (2 per cent).	Ammonia.	.14	.00	.00	− .28	− .56	.00	.92	1.12	.56
Do.	Nitrates.	− 1.40	5.29	4.34	− 1.10	5.18	4.90	− 1.54	− 4.08	2.38
Field corn (2 per cent).	Ammonia.	− .28	.70	.00	− .14	.00	2.52	.42	.00	.28
Do.	Nitrates.	− 1.54	.67	4.76	.96	1.58	2.10	Lost.	− 5.60	1.12
Sorghum (2 per cent).	Ammonia.	− .35	.00	1.26	− .00	.14	.14	.28	.70	.28
Do.	Nitrates.	− 1.12	.11	.98	− 1.24	.28	− .84	− 1.40	− 3.78	− 1.40
Alfalfa (2 per cent).	Ammonia.	3.36	1.40	1.40	6.02	2.80	4.06	11.20	5.46	2.36
Do.	Nitrates.	18.34	23.35	28.84	6.46	12.04	11.62	3.78	3.92	13.72
Water only	Ammonia.	1.40	1.26	1.54	1.26	1.26	1.26	1.12	.70	1.12
Do.	Nitrates.	1.96	3.25	2.40	1.66	3.22	2.38	1.96	2.60	2.66
		Plot B.			Plot C.			Plot E.		
Dried blood (1 per cent).	Ammonia.	45.50	49.28	39.06	28.56	29.82	22.26	43.40	35.14	26.32
Do.	Nitrates.	− .70	− 3.12	.00	7.28	17.08	18.68	4.20	17.22	16.16
Sweet corn (2 per cent).	Ammonia.	.56	.56	− .70	.56	.00	.00	00	.00	− .28
Do.	Nitrates.	− .14	.56	3.71	− 1.96	3.64	2.59	− .84	− 1.68	− 1.40
Field corn (2 per cent).	Ammonia.	.21	− .04	− .84	.28	.00	− .07	− .28	− .28	.14
Do.	Nitrates.	− .14	− 4.06	1.75	− 1.96	2.66	.14	− .84	− .14	1.26
Sorghum (2 per cent).	Ammonia.	.21	− .42	− .28	.42	.56	.98	− .42	.14	− .84
Do.	Nitrates.	− .14	− 2.16	− .77	− 1.96	.14	− 2.38	− .70	− 1.12	− 1.96
Alfalfa (2 per cent).	Ammonia.	13.44	5.60	3.22	4.76	3.50	2.10	4.06	3.50	1.68
Do.	Nitrates.	2.94	16.24	13.30	6.16	12.32	14.28	3.78	18.62	14.14
Water only	Ammonia	.70	1.12	1.38	.84	.98	1.26	1.40	1.26	1.24
Do.	Nitrates.	.56	3.16	1.11	2.52	2.52	3.08	1.54	3.78	2.80

The addition of 1 per cent of dried blood caused a marked increase in ammonia in all of the soils. At the conclusion of the six weeks' incubation period, from 12.14 to 29.80 per cent of the nitrogen added as dried blood was recovered as ammonia. Nitrification proceeded rapidly during the first 14 days in soil U and somewhat slower in soils C and E, while soils B, F, and H showed a slight reduction in nitrates at this time. Soils B and H showed no increase in nitric nitrogen over the control at any time during the experiment and the gain in soil F amounted to only 2.94 mgm. The only soil in which the amount of nitric nitrogen exceeds the amount of ammonia recovered from the soil is soil U, and in this soil only 36.12 per cent of the nitrogen added in dried blood was recovered as nitrates. A large part of the nitrogen added as dried blood was apparently lost in all of the soils.

TABLE IX.—*Percentage of nitrogen added to soils in dried blood and green manures recovered as ammonia and nitrates after six weeks' incubation; also percentage gain or loss of nitrogen added. November 4, 1914*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Material added.	Nitrogen in material added.	Nitrogen as ammonia recovered in 6 weeks.	Percentage of nitrogen as ammonia recovered.	Nitrogen as nitrate recovered in 6 weeks.	Percentage of nitrogen as nitrate recovered.	Nitrogen remaining in soil after 6 weeks.	Gain or loss in nitrogen.	Percentage of nitrogen gained or lost.
PLOT U								
Dried blood (1 per cent)	137.20	16.66	12.14	49.56	36.12	112.00	−25.20	−18.37
Sweet corn (2 per cent)	32.20	.00	.00	4.34	13.48	37.80	5.60	17.39
Field corn (2 per cent)	29.40	.00	.00	4.76	16.19	39.20	9.80	33.33
Sorghum (2 per cent)	23.20	1.26	5.43	.98	4.22	36.40	13.20	56.90
Alfalfa (2 per cent)	84.80	1.40	1.65	28.84	34.01	87.55	2.75	3.24
PLOT F								
Dried blood (1 per cent)	137.20	28.98	21.12	2.94	2.14	66.00	−71.20	−51.90
Sweet corn (2 per cent)	32.20	.00	.00	4.90	15.22	32.20	.00	.00
Field corn (2 per cent)	29.40	2.52	8.57	2.10	7.14	30.80	1.40	4.73
Sorghum (2 per cent)	23.20	.14	.60	− .84	− 3.62	24.15	.95	4.09
Alfalfa (2 per cent)	84.80	4.06	4.79	11.62	13.70	79.50	− 5.30	− 6.25
PLOT H								
Dried blood (1 per cent)	137.20	40.88	29.80	−1.68	− 1.22	61.90	−75.30	−54.88
Sweet corn (2 per cent)	32.20	.56	1.74	2.38	7.39	30.45	− 1.75	− 5.44
Field corn (2 per cent)	29.40	.28	.95	1.12	3.81	36.40	7.00	23.81
Sorghum (2 per cent)	23.20	.28	1.21	−1.40	− 6.04	24.50	1.30	5.60
Alfalfa (2 per cent)	84.80	3.36	3.96	13.72	16.18	85.10	.30	.35
PLOT B								
Dried blood (1 per cent)	137.20	39.06	28.47	0.00	0.00	64.90	−72.30	−52.70
Sweet corn (2 per cent)	32.20	− .70	−2.18	3.71	11.52	31.85	− .35	− 1.08
Field corn (2 per cent)	29.40	− .84	−2.86	1.75	5.95	29.05	− .35	− 1.19
Sorghum (2 per cent)	23.20	− .28	−1.21	− .77	− 3.32	24.15	.95	4.09
Alfalfa (2 per cent)	84.80	3.22	3.80	13.30	15.68	79.50	− 5.30	− 6.25
PLOT C								
Dried blood (1 per cent)	137.20	22.26	16.22	18.68	13.62	75.60	−61.60	−44.90
Sweet corn (2 per cent)	32.20	.00	.00	2.59	8.05	26.95	− 5.25	−16.31
Field corn (2 per cent)	29.40	− .07	− .24	.14	.48	37.10	7.70	26.19
Sorghum (2 per cent)	23.20	.98	4.22	−2.38	−10.26	22.40	− .80	− 3.45
Alfalfa (2 per cent)	84.80	2.10	2.48	14.28	16.84	80.40	− 4.40	− 5.19
PLOT E								
Dried blood (1 per cent)	137.20	26.32	19.18	16.16	11.78	72.80	−64.40	−46.94
Sweet corn (2 per cent)	32.20	− .28	− .87	−1.40	− 4.35	31.15	− 1.05	− 3.26
Field corn (2 per cent)	29.40	.14	.48	1.26	4.29	36.05	6.65	22.62
Sorghum (2 per cent)	23.20	− .84	−3.62	−1.96	− 8.45	33.60	10.40	44.83
Alfalfa (2 per cent)	84.80	1.68	1.98	14.14	16.67	82.60	− 2.20	− 2.59

The addition of 2 per cent of sweet corn caused little or no increase in the ammonia content of the soils. At the end of the first 14 days all of the soils showed a reduction in nitrates; but during the latter part of the incubation period an increase in nitrates was found in all of the soils, with the exception of soil E, which showed a slight reduction in nitrates throughout the incubation period. However, the percentage of nitrogen recovered as nitrates was comparatively low in all cases. The only gain in nitrogen from the addition of sweet corn was in soil U, in which the gain amounted to 17.39 per cent of the nitrogen added. In the other soils there is apparently a loss of nitrogen varying from 1.08 per cent in soil B to 16.31 in soil C.

The production of ammonia and nitrates from field corn was very similar to that secured from the addition of the same quantity of sweet corn; but the effect on the total nitrogen content of the soil was apparently quite different in that all of the soils, with the exception of soil B, showed considerable increase in total nitrogen, the loss in soil B being only 1.19 per cent of the nitrogen added.

The addition of sorghum frequently caused a reduction of the ammonia content of the soils, and in no case does the increase amount to more than 1.26 mgm. per 100 gm. of soil. The sorghum generally caused a reduction in the nitrate content of the soils. There is an increase in total nitrogen in all of the soils except C, in which the loss amounts to 3.45 per cent of the nitrogen added.

The addition of 2 per cent of alfalfa caused a considerable increase in the ammonia content of all of the soils. At the conclusion of the experiment from 1.65 to 4.79 per cent of the nitrogen added was recovered as ammonia. The nitrification of alfalfa proceeded rapidly during the first 14 days in soil U and more slowly in the other soils. After six weeks' incubation 13.7 per cent of the nitrogen added in alfalfa was recovered as nitrates in soil F and as much as 34.01 per cent in soil U.

In the control samples in this series, as in the early experiment, the ammonia content remained fairly uniform throughout the experiment, but there was considerable variation in the nitrates.

EFFECT OF TEMPERATURE AND LARGE AND SMALL APPLICATIONS OF DRIED BLOOD ON THE NITRIFYING POWER OF SEMIARID SOILS

In the nitrification experiments reported above it was found that the soils frequently failed to nitrify dried blood when it was added in 1 per cent quantities. The determination of nitric nitrogen in these soils in the field at frequent intervals showed that the application of dried blood as a fertilizer invariably increased the nitrate content of the soil. It would seem that the difference in nitrifying power exhibited by the soils in the field and under laboratory conditions was probably due to the smaller application of dried blood under the field conditions, or possibly in some measure to the difference in temperature. In order to test the

effect of temperature and also the effect of large and small quantities of dried blood upon the nitrifying power of these soils, samples of soil were collected from each of eight plots, as shown in Table X. After thoroughly mixing and removing gravel and roots, etc., six portions, each equivalent to 1 kgm. of dry soil, were weighed out from each soil.

TABLE X.—*Nitrifying power of soils in incubator at 28° C. and in field at 17° to 20° C. March 2, 1915*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Incubation period.	Material added.	Constituent.	Plot B.	Plot T.	Plot C.	Plot S.	Plot F.	Plot O.	Plot E.	Plot U.
At beginning of experiment.	....	Ammonia.	0.39	0.60	0.32	0.88	0.50	0.67	0.53	0.53
		Nitrates...	.18	.18	.22	.36	.57	.43	.29	.25
After 14 days' incubation at 28° C.	No nitrogen added.	Ammonia.	.60	.62	.60	.78	.52	.72	.42	.84
	....do.......	Nitrates...	.48	.81	.46	.95	1.16	1.34	.46	.98
	0.1 per cent dried blood added.	Ammonia.	1.82	.18	1.40	.70	.72	.00	.00	.20
	....do.......	Nitrates...	6.72	6.09	6.26	7.[illegible]7	7.42	6.93	7.00	7.60
	1.0 per cent dried blood added.	Ammonia.	84.70	89.04	74.20	52.22	77.56	57.94	74.20	56.28
	....do.......	Nitrates...	.00	.91	.00	26.11	14.00	20.65	11.62	21.21
After 28 days' incubation at 28° C.	No nitrogen added.	Ammonia.	.74	1.02	.60	1.04	.60	.88	.74	.74
	....do.......	Nitrates...	.53	.88	.32	1.37	1.58	1.93	.53	1.09
	0.1 per cent dried blood added.	Ammonia.	1.68	.18	.14	.14	.28	.14	.14	.14
	....do.......	Nitrates...	6.65	7.08	7.42	7.07	6.72	7.07	7.79	7.42
	1.0 per cent dried blood added.	Ammonia.	84.56	86.24	78.34	51.24	58.94	51.80	63.56	40.14
	....do.......	Nitrates...	.00	4.90	.00	33.30	28.44	30.87	24.99	49.59
After 28 days' in the field at 17–20° C.	No nitrogen added.	Ammonia.	1.02	Lost.	.74	Lost.	.74	.74	.60	.60
	....do.......	Nitrates...	.71	1.12	.46	1.54	1.54	1.54	.49	.83
	0.1 per cent dried blood added.	Ammonia.	1.71	[a] 2.24	.28	[a] 1.30	.00	.56	.28	.14
	....do.......	Nitrates...	6.33	5.92	8.26	7.42	6.86	6.86	8.22	8.68
	1.0 per cent dried blood added.	Ammonia.	61.04	[a] 36.30	71.96	[a] 43.58	33.60	26.60	44.10	28.70
	....do.......	Nitrates...	3.56	28.00	3.15	30.80	30.84	33.60	29.08	37.16
After 56 days' incubation at 28° C.	No nitrogen added.	Ammonia.	1.06	.84	.56	.84	.84	1.08	.68	.68
	....do.......	Nitrates...	1.20	2.10	1.06	2.80	2.94	3.50	1.20	2.80
	0.1 per cent dried blood added.	Ammonia.	.06	1.06	.56	.28	.28	−.18	−.28	−.44
	....do.......	Nitrates...	9.72	9.94	9.99	10.20	11.76	10.08	9.44	9.94
	1.0 per cent dried blood added.	Ammonia.	63.90	64.96	65.24	49.76	55.16	34.60	50.40	39.12
	....do.......	Nitrates...	−.47	24.78	−.22	43.12	28.70	56.14	37.16	47.88
After 56 days' incubation in the field at 17–20° C.	No nitrogen added.	Ammonia	.84	.70	.84	1.12	.84	.98	.94	.84
	....do.......	Nitrates..	1.74	1.68	1.26	2.24	1.96	2.35	.98	1.90
	0.1 per cent dried blood added.	Ammonia.	.24	.56	.42	.14	−.28	.14	.32	.10
	....do.......	Nitrates...	9.22	9.24	9.94	8.68	9.24	9.27	8.66	9.02
	1.0 per cent dried blood added.	Ammonia	75.22	55.98	84.22	46.48	41.72	38.78	50.30	41.72
	....do.......	Nitrates...	3.04	48.92	1.26	39.76	38.64	46.93	34.02	54.10
After 90 days' incubation at 28° C.	No nitrogen added	Ammonia.	.32	.77	.35	.92	.53	.71	.49	.45
	....do.......	Nitrates...	.95	1.79	1.30	3.19	2.92	5.15	1.51	4.03
After 90 days' in the field at 17–20° C.	No nitrogen added.	Ammonia.	.46	.77	.42	1.13	.56	.71	.56	.53
	....do.......	Nitrates...	1.16	1.72	1.51	3.77	2.85	3.96	1.65	3.05

[a] Ammonia in the control not subtracted.

At the time the samples were taken the ammonia in the eight soils varied from 0.32 mgm. in soil C to 0.88 mgm. in soil S. There was little change in the ammonia content of the control samples at any time during the incubation period of 90 days, whether the samples were held in the incubator at 28° C. or in the field at 17° to 20°.

The nitric nitrogen in the soils at the time the samples were taken varied from 0.18 mgm. in soils B and T to 0.57 mgm. in soil F. After 14 days' incubation at 28°, the control samples showed an appreciable increase in nitrates. From 14 to 28 days there appears to have been little additional increase in soils B, T, C, E, and U. On comparing the nitrates in the control samples after 28 days' incubation in the two series, it appears that the increase in nitrates is about the same, regardless of the temperature at which the soils were held. From 28 to 56 days there is a rather marked increase in nitrates in the control samples in the incubator and also in the field. From 56 to 90 days there was a still further increase in nitrates in most instances; and on comparing the nitrates found in the samples held in the incubator and samples held in the field, it appears that the difference in temperature has had little effect on the increase in nitrates in these soils.

When 0.1 per cent of dried blood was added, there was an increase in the ammonia after 14 days in all of the soils except O and E. After 28 days' incubation the soils receiving 0.1 per cent of dried blood contained only a little more ammonia than the control samples. It would seem that the difference in temperature had little or no effect on the accumulation of ammonia in the soils at any time during the incubation period of 56 days, when 0.1 per cent of dried blood was added. There was a marked increase in nitrates in all of the soils receiving 0.1 per cent of dried blood after 14 days' incubation at 28°. On comparing the amount of nitrates found in the soils held at 28° and those held at from 17° to 20°, it is seen that the amount of nitrates produced from 0.1 per cent of dried blood is quite uniform in all of the soils, and it would seem that the difference in temperature has not been an influential factor in determining the rate of nitrification.

The addition of 1 per cent of dried blood caused a very large increase in ammonia. After 14 days' incubation at 28°, the ammonia varied from 56.28 mgm. in soil U to 89.04 mgm. in soil T. From 14 to 28 days there appears to have been a slight reduction in the ammonia content of some of the soils, although it is still extremely high in all cases. On comparing the amount of ammonia found in the soils held in the incubator and those held in the field soils, it would seem that the soils held in the incubator contained somewhat more ammonia. After 56 days the ammonia is still high in all of the soils, whether held in the incubator or in the field, thus indicating that nitrification has been very incomplete, even after 56 days' incubation.

The increase in nitrates from the addition of 1 per cent of dried blood after 14 days' incubation varies from 0 in soils B and C to 26.11 mgm. in

soil S. From 14 to 28 days there was an increase in nitrates in all soils except B and C, which continued to show no increase in nitrates when held at 28°; when held in the field at a temperature of 17° to 20°, these two soils showed gains of 3.56 and 3.15 mgm., respectively. After 56 days a somewhat smaller amount of nitric nitrogen was found in soils B and C than in the control samples, when held at 28°, but the increase in the other soils varies from 24.78 mgm. in soil T to 56.14 in soil O. When held at a temperature of 17° to 20° for 56 days, soils B and C showed an increase of 3.04 and 1.26 mgm., respectively. Soil T also showed a much higher nitrifying power when held at the lower temperature, but in the other soils the influence of temperature within the range of the experiment does not seem to have been an important factor.

From the data presented in Tables I to X it is obvious that the nitrifying power of a soil as determined in the laboratory by the addition of the usual amount of dried blood may be very different from that exhibited by the soil under the field conditions, and the results secured must therefore be interpreted with great care. The data presented in Table X show that, on the addition of 1 per cent of dried blood, soils B and C failed to give any increase in nitric nitrogen, even after 56 days' incubation; but, on the addition of 0.1 per cent of dried blood, these two soils nitrified as rapidly as the other soils.

It is observed that both of the virgin soils failed to nitrify 1 per cent of dried blood, while many of the soils cultivated for some years nitrified this amount of dried blood very rapidly. The power of southern California soils to nitrify 1 per cent of dried blood seems to be rather closely correlated with the character of the organic content. Those soils which have received additions of organic materials frequently nitrify 1 per cent of dried blood when the adjacent virgin soil or cultivated soils which have received no organic matter fail to give any increase in nitrates. Even those plots which have received only dried blood or bone meal frequently nitrify 1 per cent of dried blood, while the virgin soil, or soil from plots which have received no nitrifiable matter, fails to give any increase in nitrates.

In semiarid soil the growth of native vegetation is frequently very limited, owing to the meager rainfall, and the organic content of many virgin lands is consequently very low. It is well known that the proper physical, chemical, and biological characters of a soil are largely dependent upon the presence of organic matter. It therefore seems reasonable to suppose that the process of nitrification, which is so closely associated with the decomposition of organic matter, should become weakened and fail to function properly under abnormal conditions, such as are obviously produced by the large accumulation of ammonia which invariably follows the addition of 1 per cent of dried blood.

The results presented above indicate that the use of leguminous crops may be of great value not only in maintaining active organic matter in the soil but also in maintaining the nitrogen supply. In Tables I to IX

it is shown that the nitrification of green manure, especially the legumes, proceeds very rapidly. If green manures are incorporated with the soil at the proper stage of maturity, it would seem that some increase in nitric nitrogen may be expected during the first seven days and that a large percentage of the nitrogen contained in the crop will be converted into nitrates within 30 days. Early spring would seem to be the season when it is most important to have an abundant supply of available nitrogen in Citrus soils. It therefore seems inadvisable to allow the cover crop to develop until late spring, as it not only robs the tree of its nitrogen supply at a critical season but as the crop becomes more mature the nitrogen which it contains is converted into nitrates more slowly after it is plowed down. Even if a cover crop is not grown, the winter rains may carry the nitrate below the feeding roots of the trees. The rapidity of nitrification in the early spring would therefore seem to be of special importance with Citrus crops, as the nitrate content of Citrus lands is likely to be very low at that time.

The results presented above also indicate that the growth of cover crops may materially assist in maintaining the total nitrogen content of the soils. Under favorable conditions it would seem that the nitrogen gained by cover crops may more than pay for the additional cost in operation. They may also save much nitrogen from leaching away during the winter season.

In the above tables it is shown that, when 1 per cent of dried blood is added to soils, much of the nitrogen added is lost. In some cases less than 50 per cent of the nitrogen added could be recovered after six weeks' incubation. When taken from the incubator, the soils frequently gave off a strong odor of ammonia, and it is believed that much or possibly all of the loss occurred through the volatilization of ammonia. It is recognized that the determinations of the ammonia content of the soils to which 1 per cent of dried blood was added do not show the quantity of ammonia produced but rather the ammonia remaining in the soil at the time the analyses were made. Determinations of nitrites were not made, except in a few instances; but these few determinations were sufficient to show that considerable quantities of nitrites sometimes accumulated in these soils following the addition of 1 per cent of dried blood. As the reduction method was used in determining the nitric nitrogen, it is likely that some of the nitrogen recorded as nitrates may have been present as nitrites.

EFFECT OF FURROW IRRIGATION ON THE DISTRIBUTION OF NITRIC NITROGEN IN SOILS

In the irrigation of land many methods of applying the water are now in use; but, as a rule, the furrow system is employed in the irrigation of orchards, small fruits, root crops, and vegetables. In the irrigation of orchards the furrows may vary from 4 to 9 inches in depth, and the number of furrows run between adjacent tree rows may vary from 2 to 6. The

water which is distributed in the furrows quickly passes under the forces of gravity and capillarity. The downward movement of the water is frequently interrupted by a rather impervious plowsole; under such conditions the capillary forces cause a rapid lateral movement of the water, and in the course of a few hours the moisture may spread to all of the intervening space between the furrows. The action of the capillary forces is of paramount importance in securing an even distribution of water; but these forces, operating under the conditions mentioned above, while giving an even distribution of moisture, may have the reverse effect upon the soluble salts in the soil, especially the highly soluble salts, such as the nitrates, which possess a relatively high order of diffusibility.

The investigations in the distribution of nitrates in furrow-irrigated soils was commenced in July, 1913, and during the latter part of the season several hundred samples of soil were collected from furrow-irrigated Citrus groves in Riverside County. The analyses indicated an extremely uneven distribution of nitrates in these soils. Surface scrapings collected from brown spots, which generally occur in furrow-irrigated soils immediately after irrigation, frequently showed a nitrate content amounting to more than 0.5 per cent of nitrogen, while samples taken a few inches immediately beneath the brown spots were invariably low in nitrates and not uncommonly contained as little as 1 part per million. The very large amount of nitric nitrogen in the brown spots led to a study of the vertical distribution of the nitrates in 6-inch sections. The analyses indicated that in many groves as much as 75 per cent of the nitrate in the upper 3 feet was confined to the surface 6 inches of soil during the summer months.

Because of the frequent cultivation of Citrus groves, very few feeding roots were found in the upper 6 inches of soil. It therefore appears that the large store of available nitrogen found in the surface layers can be of little value in the nutrition of Citrus plants until carried down within reach of the feeding roots. The investigation of the vertical distribution of nitric nitrogen was continued during the winter months, and it was observed that the nitrates began to move downward as soon as the winter rains were sufficient to penetrate the soil to a greater depth than 6 inches. At the end of the rainy season the nitrates in the surface layers were extremely low. After the beginning of the rainy season there was no evidence of the brown spots, which had been so characteristic after every irrigation. However, as soon as the irrigation of the new season began, the brown coloration was again in evidence, though not so abundant as during the latter part of the previous season. Analyses of scrapings from the brown spots again showed them to be typical niter spots. During the spring and summer months extensive investigations were carried out on the nitrifying and nitrogen-fixing power of these soils. No correlation could be established between the high nitric content of the surface soil and the activity of the nitrifying or nitrogen-fixing organisms, but the field observations and preliminary laboratory studies seemed to show that there was a close correlation between the irrigation and the occur-

rence of the niter spots. The irrigation water was carefully analyzed and found to contain very small quantities of nitrates, which seemed to preclude the possibility of irrigation water being the source of the nitrates; neither did it seem at all possible that the nitrate accumulations in the Citrus soils of southern California could be derived from nitrate deposits occurring originally in the country rock. The rock from which these soils were originally derived are granitic in character, and, so far as the writer has been able to ascertain, contains little or no nitrogen. Furthermore, the virgin lands or cropped dry lands are generally very low in nitrogen and do not contain the brown spots so characteristic of furrow-irrigated lands.

Table XI.—*Seasonal variation in nitrates in furrow-irrigated soils receiving heavy applications of nitrogenous fertilizers. September, 1914, to August, 1915, inclusive*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Period.	Plot A.				Plot C.				Plot F.			
Depth............inches..	0–6	6–18	18–30	30–42	0–6	6–18	18–30	30–42	0–6	6–18	18–30	30–42
1914.												
September	5.18	0.74	0.46	......	5.22	1.02	0.60	......	2.70	0.60	0.32	......
October	4.14	.46	.46	......	4.28	.84	.46	......	1.98	.57	.32	......
November	3.60	.39	.25	......	3.84	.97	.25	......	1.44	.32	.18	......
December	4.72	.59	.18	......	2.61	.94	.18	......	1.63	.81	.25	......
1915.												
January	3.51	.88	.18	......	2.72	1.02	.11	......	1.30	.43	.29	......
February	.15	.53	1.09	......	.25	.39	1.23	......	.25	.29	.83	......
March	1.58	.88	.46	0.16	.46	.32	.25	0.82	.32	.29	.32	0.32
April	2.08	.88	.58	.85	.95	.39	.71	1.02	.60	.36	.25	.29
May	.31	.62	.51	.17	.20	.65	.37	.28	.58	.58	.22	.25
June	1.99	.57	.20	.29	1.77	.35	.22	.15	1.10	.22	.18	.08
July	3.05	.25	.29	.29	2.60	.25	.29	.11	1.30	.11	.15	.08
August	2.51	.22	.06	.06	3.96	.18	.10	.08	1.09	.39	.18	.11
	Plot G.				Plot H.				Plot L.			
1914.												
September	6.62	0.74	0.46	......	7.18	1.16	0.60	......	5.78	0.98	0.74	......
October	5.22	.74	.46	......	6.55	.57	.74	......	4.60	.74	1.02	......
November	4.54	.66	.18	......	4.68	.74	.46	......	3.65	.32	.25	......
December	4.17	1.13	.29	......	4.59	1.30	.25	......	3.75	.99	.18	......
1915.												
January	3.53	.74	.18	......	4.82	1.51	.25	......	3.23	1.22	.15	......
February	.25	1.10	1.71	......	.22	1.03	1.74	......	.11	1.06	1.64	......
March	2.40	.66	.81	0.67	2.65	1.15	.92	0.95	1.98	.39	.74	0.99
April	2.76	.77	.84	.53	2.80	.60	.53	.87	2.12	.60	.71	1.02
May	.69	.95	.20	.13	.50	.36	.30	.49	.43	.54	.36	.57
June	3.52	.86	.50	.59	4.21	.78	.64	.97	2.32	.57	.64	.50
July	2.27	.13	.28	.04	3.33	.39	.32	.60	2.39	.64	.46	.46
August	4.38	.30	.78	.60	3.95	.46	.48	.56	3.54	.39	.71	1.16
	Plot O.				Plot Q.				Plot S.			
1914.												
September	2.42	0.74	0.46	......	4.98	0.88	0.60	......	4.70	1.30	0.74	......
October	1.94	.46	.74	......	4.42	.74	.74	......	4.10	1.02	1.02	......
November	1.04	.43	.46	......	3.78	1.02	.32	......	3.82	1.02	.53	......
December	1.74	.66	.25	......	3.48	1.78	.18	......	3.05	1.79	.38	......
1915.												
January	2.00	.60	.32	......	3.57	1.23	.32	......	3.91	1.44	.43	......
February	.25	.48	.86	......	.50	2.18	.99	......	.67	1.79	1.16	......
March	.25	.25	.67	0.54	1.85	1.02	1.30	1.09	.81	.81	1.09	1.08
April	.53	.36	.56	.56	2.45	1.23	1.44	.74	1.30	.81	1.10	1.08
May	.64	.46	.41	.36	.60	.60	.48	.34	.20	.57	.59	.67
June	1.41	.36	.27	.50	2.73	.85	.79	.81	2.00	1.09	.78	.95
July	1.79	.32	.25	.15	3.72	.46	.29	.39	3.58	.53	.60	.60
August	1.51	.25	.08	.18	3.12	.53	.74	.16	2.35	.29	.92	.53

In September, 1914, systematic studies were undertaken, in cooperation with the Citrus Experiment Station, to determine more accurately the distribution and movement of nitric nitrogen in Citrus soils and the factors controlling the same. Table XI shows the vertical distribution of nitric nitrogen in nine Citrus soils, receiving heavy applications of nitrogenous fertilizers.

A comparison of the amount of nitric nitrogen found in the upper 6 inches of soil in September shows that the nitrate content of the upper 6 inches is many times that found at a depth of from 6 to 18 inches or 18 to 30 inches. A similar distribution of nitric nitrogen is found in these plots during the months of October, November, December, and January. In February the quantity of nitric nitrogen in the upper 6 inches was found to be very much lower than during the previous months. The maximum amount found at this time is in plot S and amounts to 0.67 mgm. per 100 gm. of soil. In plot H the quantity in the upper 6 inches has been reduced to 0.22 mgm. It is seen that, while the amount of nitric nitrogen in the surface 6 inches has decreased, the amount at a depth of 18 to 30 inches has increased in all cases. It is therefore obvious that the nitric nitrogen has moved downward since the sampling in January. During the time intervening between the samplings the rainfall amounted to 6.52 inches, and it would seem that this precipitation was sufficient to move to below a depth of 30 inches much of the nitric nitrogen which had accumulated at the surface during the irrigation season. In March the nitric nitrogen content in the upper 6 inches is much increased in plots A, G, H, L, and Q. This increase is apparently due to the first application of fertilizer, added on February 14, which included sodium nitrate. Dried blood applied to plots C and Q or barnyard manure applied to plots F and O gives little or no increase in nitric nitrogen at this time. In April all plots show an increase in the upper 6 inches, although the gain in the manured plots is very small, indicating that the nitrogen in the manure becomes available very slowly. The plots were irrigated from April 15 to 18. Following the irrigation 2.20 inches of rain fell. It appears from the data secured that the combined effect of the irrigation and rainfall between the samplings in April and May caused a marked downward movement of the nitric nitrogen, so that none of the plots showed any concentration of nitrates in the surface 6 inches. Even at a depth of 30 to 42 inches the nitrates were much lower than during the previous month, indicating a downward movement below 3½ feet. The second and third applications of fertilizer were applied on May 8 and July 2, respectively. As the season advanced it was observed that there was a marked accumulation of nitrates in the upper 6 inches, but no increase in the lower layers. The distribution throughout the year indicates that the application of water in furrows has very little effect in carrying nitric nitrogen down, but that rainfall, when sufficient to penetrate the soil to considerable depth, is very effective in causing a downward movement of nitrates and other soluble salts.

Table XII shows the distribution of nitric nitrogen in soils receiving light applications of nitrogenous fertilizers, and in these soils it is seen that the accumulation of nitric nitrogen in the surface 6 inches is far less than in the heavily fertilized soils. It is also seen that the amount found at a depth of 6 to 18, 18 to 30, and 30 to 42 inches is somewhat lower than in the heavily fertilized soils. The effect of the rainfall in carrying down the nitrates is shown in the results on the lightly fertilized soils as well as on the heavily fertilized soils. The smaller percentage accumulation of nitrates at the surface during the irrigation season is probably due to the fact that all of the materials added to the lightly fertilized plots was added in one application in the early spring and plowed down, and as the amount added was not in excess of the needs of the tree, much of the nitrogen was probably assimilated before the upward movement of the soil moisture had carried it beyond reach of the roots.

Table XII.—*Seasonal variation in nitrates in furrow-irrigated soils receiving light applications of nitrogenous fertilizers. September, 1914, to August, 1915, inclusive*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Period.	Plot E.				Plot N.			
Depth.......inches..	0–6	6–18	18–30	30–42	0–6	6–18	18–30	30–42
1914.								
September	0.88	0.46	0.52	....	1.02	0.11	0.46	....
October	.88	.57	.46	....	1.02	.46	.32	....
November	1.02	.32	.18	....	1.14	.32	.25	....
December	1.16	.53	.22	....	1.02	.15	.18	....
1915.								
January	.97	.25	.11	....	.78	.39	.18	....
February	.18	.29	.39	....	.15	.22	.25	....
March	.50	.21	.29	0.32	.58	.11	.05	0.01
April	1.37	.22	.18	.25	1.44	.43	.33	.24
May	.55	.84	.29	.13	.69	.36	.18	.11
June	1.30	.29	.25	.08	.61	.18	.11	.04
July	1.06	.22	.22	.15	1.02	.18	.15	.15
August	1.02	.11	.08	.08	1.05	.15	.11	.08
	Plot K.				Plot P.			
1914.								
September	1.02	0.46	0.46	....	1.38	0.46	0.46	....
October	1.02	.46	.74	....	1.16	.46	.47	....
November	1.02	.32	.18	....	1.14	.18	.25	....
December	.99	.32	.11	....	1.02	.46	.25	....
1915.								
January	.91	.22	.11	....	.83	.22	.11	....
February	.15	.18	.60	....	.18	.32	.28	....
March	.81	.25	.32	....	.88	.25	.11	....
April	1.44	.46	.32	0.32	1.44	.53	.25	0.18
May	.57	.54	.25	.22	.53	.53	.34	.41
June	1.32	.46	.11	.04	1.08	.06	.10	.08
July	99	.18	.15	.18	.61	.25	.25	.08
August	1.51	.36	.15	.01	1.02	.11	.11	.11

By a comparison of the results presented in Table XIII with those of Tables XI and XII the effect of the application of the nitrogenous fertilizers may be readily ascertained. The nitrate content of the heavily fertilized plots at a depth of 0 to 6 inches is far in excess of the amount found in the unfertilized plots. At a depth of 6 to 18 inches, 18 to 30 inches, and 30 to 42 inches the increase is much less marked, and in some

instances little or no increase is found. The light application of nitrogenous fertilizer has apparently increased the nitrate content of the soil very little over the unfertilized plots. This, of course, does not necessarily mean that the application of the nitrogenous fertilizers to these plots has not resulted in an increased nitrate supply, but rather that the nitrate has been assimilated almost as rapidly as formed. The character of the trees on these plots shows that the light application of nitrogenous fertilizer has resulted in the development of a larger and more thrifty tree than those produced by the control plots. The trees on the lightly fertilized plots have also produced more and better fruit.

TABLE XIII.—*Seasonal variation in nitrates in furrow-irrigated soils receiving no nitrogenous fertilizers. September, 1914, to August, 1915, inclusive*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Period.	Plot B.				Plot D.				Plot I.			
Depth ....inches..	0–6	6–18	18–30	30–42	0–6	6–18	18–30	30–42	0–6	6–18	18–30	30–42
1914.												
September	0.94	0.46	0.46	......	1.00	0.32	0.18	......	0.74	0.46	0.18	......
October	.92	.18	.32	......	1.20	.32	.32	......	.88	.32	.32	......
November	.76	.15	.11	......	.95	.15	.18	......	.62	.25	.18	......
December	.88	.25	.18	......	.88	.32	.22	......	.62	.36	.25	......
1915.												
January	.75	.25	.11	......	.76	.25	.11	......	.57	.18	.18	......
February	.11	.15	.25	......	.15	.11	.29	......	.11	.22	.18	......
March	.11	.15	.08	.11	.18	.18	.25	.11	.17	.08	.11	0.04
April	.22	.08	.11	.14	.25	.18	.18	.18	.32	.11	.11	.18
May	.06	.34	.04	.08	.04	.29	.08	.04	.08	.29	.08	.03
June	.26	.13	.08	.04	.39	.04	.04	.22	.11	.03	.32	.25
July	.46	.11	.11	.08	.74	.18	.11	.04	.53	.11	.11	.11
August	.67	.04	.08	.04	.96	.15	.08	.01	1.48	.04	.04	.01

Period.	Plot J.				Plot M.				Plot R.			
1914.												
September	0.74	0.46	0.46	......	1.02	0.60	0.46	......	1.02	0.46	0.32	......
October	1.02	.46	.46	......	.88	.46	.18	......	1.02	.46	.74	......
November	.95	.18	.18	......	.60	.50	.11	......	.90	.38	.18	......
December	.69	.59	.18	......	.66	.25	.18	......	.81	.39	.11	......
1915.												
January	.53	.18	.11	......	.70	.25	.11	......	.70	.18	.11	......
February	.15	.32	.25	......	.08	.25	.18	......	.18	.44	.22	......
March	.18	.25	.18	.18	.18	.08	.15	Lost.	.18	.11	.25	0.18
April	.39	.46	.32	.25	.46	.32	.46	.11	.53	.39	.36	.25
May	.08	.29	.08	.03	.11	.32	.22	.17	.20	.30	.09	.11
June	.53	.04	.04	.11	.53	.11	.04	.11	.25	.10	.20	.08
July	.88	.39	.11	.18	.53	.18	.18	.11	.43	.15	.11	.14
August	.64	.15	.08	.04	.46	.04	.04	.08	.46	.11	.11	.08

Period.	Plot T.			
Depth ....inches..........	0–6	6–18	18–30	30–42
1914.				
September	1.02	0.74	0.46	....
October	1.07	.46	.46	....
November	1.10	.32	.15	....
December	1.09	.25	.11	....
1915.				
January	.88	.25	.15	....
February	.32	.24	.25	....
March	.61	.52	.22	0.50
April	.60	.53	.30	.32
May	.11	.36	.18	.11
June	.32	.04	.04	.04
July	.71	.25	.18	.25
August	.25	.08	.08	.03

The effect of rainfall in causing a downward movement of nitric nitrogen is seen to have taken place in the unfertilized plots as well as in the fertilized.

In Tables XI to XIII it was seen that the effect of the application of nitrogenous materials to the soils invariably increased the nitrate content of the soil, especially the surface layers; and it was also seen that the nitrates were very completely leached out of the surface layers by the winter rains, producing a rather marked seasonal variation in the nitrate content of the heavily fertilized soils.

TABLE XLV.—*Seasonal variation in ammonia in furrow-irrigated soils receiving heavy applications of nitrogenous fertilizers. September, 1914, to August, 1915, inclusive*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Period.	Plot A.			Plot C.			Plot F.		
Depth...............inches..	0-6	6-18	18-30	0-6	6-18	18-30	0-6	6-18	18-30
1914.									
September	0.74	0.74	0.46	1.02	0.74	0.46	0.74	0.46	0.46
October	.74	.74	.46	.98	.57	.32	.98	.57	.46
November	.81	.18	.11	.95	.18	.15	.66	.25	.11
December	.74	.39	.18	.87	.50	.25	.78	.39	.32
1915.									
January	.60	.46	.43	.71	.57	.46	.60	.39	.22
February	.32	.32	.18	.46	.25	.11	.67	.11	.11
March	.60	.43	.29	.81	.53	.39	.60	.29	.29
April	.64	.16	.11	.46	.22	.15	.45	.36	.15
June	.39	.22	.11	.67	.22	.11	.46	.25	.08
July	.46	.25	.15	Lost.	.29	Lost.	.60	.22	.18
August	.29	.15	.11	.36	.22	.04	.36	.11	.01
	Plot G.			Plot H.			Plot L.		
1914.									
September	1.02	0.46	0.32	0.74	0.46	0.46	1.02	0.74	0.46
October	1.02	.46	.46	1.02	.74	.46	1.02	.74	.46
November	.88	.43	.18	.88	.39	.18	1.09	.43	.15
December	.74	.50	.18	.74	.39	.32	.99	.39	.29
1915.									
January	.57	.32	.22	.60	.43	.23	.81	.60	.25
February	.39	.25	.08	.53	.32	.08	.46	.25	.08
March	.88	.39	.25	.46	.39	.25	.60	.53	.53
April	.50	.18	.18	.53	.22	.22	.64	.36	.18
June	.60	.29	.11	.60	.29	.11	.53	.25	.04
July	.57	.18	.15	.59	.29	.15	.74	.26	.25
August	.50	.11	.08	.32	.08	.01	.43	.15	.01
	Plot O.			Plot Q.			Plot S.		
1914.									
September	1.02	0.74	0.60	1.30	0.46	0.32	1.30	0.74	0.46
October	1.02	.74	.46	1.02	.78	.57	1.14	.32	.46
November	.74	.25	.18	1.14	.39	.18	1.58	.46	.32
December	.75	.53	.46	1.20	.46	.25	1.02	.53	.15
1915.									
January	1.20	.50	.46	1.02	.46	.39	1.30	.46	.39
February	.46	.32	.08	.53	.25	.04	.60	.39	.08
March	.71	.46	.39	.95	.36	.18	1.09	.46	.32
April	.53	.39	.22	.50	.51	.36	.78	.43	.39
June	.67	.25	.18	.74	.43	.32	1.06	.36	.18
July	.67	.39	.29	.81	.25	.25	1.30	.39	.15
August	.71	.22	.04	.85	.18	.11	1.13	.36	.25

Tables XIV to XVI show that the ammonia content of the soils is generally highest in the upper 6 inches, regardless of whether the soils have received heavy applications, light applications, or no nitrogenous fertilizer. It is also seen that the ammonia content of the unfertilized soils is almost, if not quite, as high as the fertilized soils, which would indicate that the ammonia formed in the decomposition processes under the field conditions does not remain in the soil, as does the ammonia formed when large applications of dried blood are added in laboratory experiments. It also appears that the rainfall has little effect on the distribution of ammonia, and a large number of data collected in later studies have shown that the lateral movements of the irrigation water, while it caused a very uneven distribution of nitrates, had very little effect on the distribution of ammonia. A comparison of the data presented in Tables XIV and XVI shows that the nitrogen as ammonia in the unfertilized soils is frequently greater than the nitrogen as nitrates; and, as the ammonia seems to be quite uniformly maintained throughout the year, its value as a source of nitrogen for Citrus plants becomes a matter of importance.

TABLE XV.—*Seasonal variation in ammonia in furrow-irrigated soils receiving no nitrogenous fertilizers. September, 1914, to August, 1915, inclusive*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Period.	Plot B.			Plot D.			Plot I.		
Depth...............inches..	0–6	6–18	18–30	0–6	6–18	18–30	0–6	6–18	18–30
1914.									
September	0.74	0.74	0.46	0.46	0.46	0.46	0.74	0.46	0.46
October	.74	.57	.46	.46	.46	.46	.57	.46	.18
November	.81	.25	.18	.10	.18	.25	.53	.53	.46
December	.69	.32	.18	.46	.39	.18	.67	.36	.25
1915.									
January	.67	.46	.43	.67	.53	.29	.67	.39	.22
February	.46	.25	.11	.39	.25	.11	.60	.46	.18
March	.46	.32	.36	.60	.39	.18	.74	.39	.25
April	.25	.22	.18	.39	.22	.11	.50	.29	.18
June	.36	.11	.04	.53	.29	.08	.60	.39	.15
July	.29	.25	.08	.39	.22	.15	.46	.32	.11
August	.22	.11	08	.25	.08	.01	.29	.18	.01

Period.	Plot J.			Plot M.			Plot R.			Plot T.		
Depth............inches..	0–6	6–18	18–30	0–6	6–18	18–30	0–6	6–18	18–30	0–6	6–18	18–30
1914.												
September	0.74	0.60	0.46	0.74	0.60	0.46	0.88	0.74	0.32	0.88	0.60	0.46
October	.74	.46	.46	.88	.57	.57	.86	.46	.32	.74	.46	.46
November	.81	.67	.25	.74	.32	.25	1.09	.60	.39	.88	.74	.32
December	.74	.46	.32	.85	.74	.46	1.09	.39	.25	.85	.36	.18
1915.												
January	.88	.67	.22	.67	.53	.25	.88	.39	.36	.67	.39	.32
February	.60	.43	.18	.53	.25	.08	.53	.25	.08	.53	.32	.04
March	.81	.36	.25	.74	53	.39	.55	.39	.25	.81	.46	.32
April	.50	.46	.29	.50	.74	.29	.57	.43	.36	1.00	.60	.37
June	.74	.39	.18	.43	.18	.25	.60	.46	.32	.67	.18	.15
July	.67	.39	.11	.60	.39	.18	.57	.25	.22	.46	.25	.15
August	.43	.18	.01	.50	.15	.01	.43	.18	.01	.39	.22	.15

TABLE XVI.—*Seasonal variation in ammonia in furrow-irrigated soils receiving light applications of nitrogenous fertilizers. September, 1914, to August, 1915, inclusive*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Period.	Plot E.			Plot N.			Plot K.			Plot P.		
Depth............inches..	0–6	6–18	18–30	0–6	6–18	18–30	0–6	6–18	18–30	0–6	6–18	18–30
1914.												
September..................	0.74	0.46	0.46	0.88	0.60	0.46	0.88	0.70	0.46	0.88	0.46	0.46
October..................	.74	.57	.57	.74	.46	.46	.74	.46	.46	.88	.46	.18
November..................	.60	.22	.18	.74	.39	.15	.67	.88	.18	.81	.39	.18
December..................	.67	.46	.18	.99	.50	.39	.74	.88	.25	.88	.46	.39
1915.												
January..................	.78	.50	.22	.71	.60	.29	.67	.46	.32	.81	.43	.36
February..................	.53	.11	.11	.46	.29	.08	.60	.39	.15	.46	.32	.08
March..................	.78	.50	.22	.63	.53	.25	.88	.43	.36	.79	.43	.15
April..................	.81	.18	.22	.99	.54	.25	.60	.29	.08	.60	.29	.15
June..................	.67	.25	.25	.74	.39	.18	.67	.32	.18	.53	.22	.15
July..................	.50	.22	.11	.60	.36	.18	.46	.29	.18	.67	.25	.18
August..................	.39	.15	.07	.44	.22	.01	.29	.11	.04	.50	.22	.08

In the preliminary studies on the distribution of nitric nitrogen under the furrow system of irrigation it was observed that the supply of nitrates near the surface was reduced near the furrows during an irrigation. However, no increase in nitrates could be detected in the deeper layers to account for the reduction which apparently took place near the surface. Before and after the June irrigation of 1915, samples were drawn, 9 inches from the furrows, from 10 plots. Each sample for analysis was made up of six borings, each one located 9 inches from a furrow. The holes made in removing the first samples were carefully filled in, and the second set of borings was made about 12 inches from the first, but the same distance from the furrows.

In order to bring out more clearly the seasonal variation and the effect of fertilizers on the nitrate and ammonia content of furrow-irrigated Citrus soils, the data presented in Tables XI to XVI are summarized in Tables XVII and XVIII.

TABLE XVII.—*Average nitrate content of Citrus Experiment Station soils. September, 1914, to August, 1915, inclusive*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Treatment and depth in inches.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
Seven plots receiving 145 pounds of nitrogen per acre in commercial fertilizers:												
0–6..................	5.67	4.77	3.98	3.77	3.62	0.31	1.68	2.07	0.42	2.65	2.99	3.40
6–18..................	.97	.73	.73	1.22	1.15	1.15	.75	.75	.61	.72	.38	.34
18–30..................	.60	.70	.32	.23	.23	1.37	.80	.84	.40	.54	.40	.54
30–42..................	......	......	......	......	......	......	.82	.87	.38	.61	.36	.45
Two plots receiving approximately 145 pounds of nitrogen per acre as barnyard manure:												
0–6..................	2.56	1.96	2.14	1.69	1.65	.25	.29	.57	.61	1.25	1.55	1.30
6–18..................	.67	.52	.37	.74	.51	.38	.27	.36	.51	.29	.22	.32
18–30..................	.39	.53	.32	.25	.30	.85	.50	.40	.31	.23	.20	.13
30–42..................	......	......	......	......	......	......	.43	.42	.30	.29	.11	.15
Four plots receiving 48.60 pounds of nitrogen per acre in commercial fertilizer:												
0–6..................	1.08	1.02	1.08	1.05	.87	.16	.69	1.42	.58	1.08	.92	1.15
6–18..................	.37	.49	.29	.37	.27	.25	.21	.41	.57	.25	.21	.18
18–30..................	.48	.50	.22	.19	.12	.38	.19	.27	.24	.14	.19	.11
30–42..................	......	......	......	......	......	......	.17	.25	.22	.06	.14	.07
Seven plots receiving no nitrogenous fertilizers:												
0–6..................	.92	.97	.84	.80	.70	.15	.23	.40	.10	.34	.61	.70
6–18..................	.50	.38	.22	.34	.22	.25	.19	.30	.31	.07	.20	.09
18–30..................	.36	.40	.16	.18	.13	.23	.18	.26	.11	.11	.13	.07
30–42..................	......	......	......	......	......	......	.19	.20	.08	.12	.13	.04

TABLE XVIII.—*Average ammonia content of Citrus Experiment Station soils. September, 1914, to August, 1915, inclusive*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Treatment and depth in inches.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	June.	July.	Aug.
Seven plots receiving 145 pounds of nitrogen per acre in commercial fertilizers:											
0–6	1.02	0.99	1.05	0.90	0.80	0.47	0.78	0.58	0.66	0.74	0.55
6–18	.61	.62	.35	.45	.47	.29	.44	.30	.29	.27	.18
18–30	.42	.46	.18	.23	.34	.09	.31	.23	.14	.18	.09
Two plots receiving approximately 145 pounds of nitrogen per acre as barnyard manure:											
0–6	.88	1.00	.70	.76	.90	.57	.66	.49	.57	.63	.54
6–18	.60	.66	.25	.46	.45	.22	.37	.38	.25	.30	.16
18–30	.53	.46	.14	.39	.34	.10	.34	.19	.13	.23	.03
Four plots receiving 48.60 pounds of nitrogen per acre in commercial fertilizer:											
0–6	.85	.78	.71	.82	.74	.51	.77	.75	.65	.56	.41
6–18	.56	.49	.47	.58	.50	.28	.47	.33	.30	.28	.18
18–30	.46	.42	.17	.30	.30	.11	.25	.18	.19	.16	.05
Seven plots receiving no nitrogenous fertilizers:											
0–6	.74	.71	.71	.76	.73	.52	.67	.53	.56	.49	.36
6–18	.60	.49	.47	.43	.48	.32	.41	.42	.28	.30	.16
18–30	.44	.41	.30	.26	.30	.11	.28	.25	.17	.12	.04

On comparing the quantity of nitric nitrogen in the surface 6 inches before and after irrigation in Table XIX, it is observed that the amount found in the second set of samples is less in every plot. The average reduction for the 10 plots amounts to a little less than 30 per cent. There is also a consistent reduction at a depth of 6 to 18 inches, which amounts to nearly 40 per cent. The average nitrate content of the plots before irrigation at a depth of 18 to 30 inches is 0.471 mgm.; after the irrigation the average for the 10 plots was only 0.272 mgm. At a depth of 30 to 42 inches the nitrate content is still somewhat lower after irrigation. The averages for all plots indicate that some movement of nitrates may have taken place at a depth of 42 to 54 inches. Below a depth of 54 inches the difference between the two sets of samples would seem to indicate that the irrigation had had little or no effect upon the distribution of the nitrates. Certainly there is no indication that the nitrates in the surface layers have been carried down into the deeper layers by the irrigation.

Since the determination of nitric nitrogen in the samples drawn 9 inches from the furrows before and after the June irrigation had shown a reduction in nitrates in the surface layers without any apparent increase in the deeper layers, it was believed that the irrigation must have caused a lateral movement, which would result in an increase in the nitrate content of the surface soil at some point farther from the furrows, presumably about midway between the furrows, as the water moving laterally from adjacent furrows would be most likely to meet near this point. As the furrows were run about 36 inches apart, samples were drawn from each of eight plots 9 inches from the furrows and 18 inches

from the furrows immediately before and as soon after the October irrigation as the moisture condition would permit. The results secured in the experiment are shown in Table XX.

Table XIX.—*Vertical distribution of nitric nitrogen before and after the June irrigation of 1915*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Depth, in inches.	Sampled before or after irrigation.	Plot. A.	C.	T.	G.	H.	L.	O.	Q.	S.	U.	Average of all plots.
0–6	Before	1.99	1.70	1.10	3.52	4.21	2.32	1.41	2.73	2.00	2.21	2.399
	After	1.39	1.16	1.01	2.74	2.25	1.58	.90	1.62	1.97	1.97	1.659
6–18	Before	.57	.35	.22	.86	.78	.57	.36	.85	1.09	1.34	.699
	After	.22	.25	.13	.60	.29	.38	.30	.67	.53	.77	.414
18–30	Before	.20	.22	.18	.50	.64	.64	.27	.79	.78	.49	.471
	After	.15	.08	.06	.42	.18	.29	.18	.62	.39	.35	.272
30–42	Before	.29	.15	.08	.59	.97	.50	.50	.81	.95	.36	.520
	After	.30	.21	.14	.46	.80	.49	.49	.50	.62	.40	.441
42–54	Before	.15	.15	.08	.78	.97	.37	.42	.71	1.02	.23	.488
	After	.21	.18	.14	.69	.68	.35	.35	.67	.70	.23	.420
54–66	Before	.11	.22	.25	.46	.94	.64	.29	1.34	.85	.20	.530
	After	.16	.18	.30	.49	.82	.66	.35	1.40	.84	.27	.537
66–78	Before	.15	.20	.11	.64	.71	.98	.49	1.34	1.13	.15	.590
	After	.24	.18	.16	.53	.86	1.14	.49	1.08	.90	.21	.579
78–90	Before	.20	.25	.20	.53	.78	.60	.29	.92	60	.13	.450
	After	.18	.27	.14	.72	.57	.64	.45	.81	.63	.15	.456
90–102	Before	.25	.18	.20	.42	.72	.29	.32	.78	.59	.15	.390
	After	.28	.28	.20	.38	.69	.50	.29	.74	.46	.15	.397
102–114	Before	1.17	.22	.18	.18	.53	.29	.....	.99	.42	.16	.414
	After	.69	.29	.18	.35	.49	.39	.....	.67	.42	.16	.364

Table XX.—*Distribution of nitrates before and after the October irrigation of 1915*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Depth in inches.	Sampled before or after irrigation.	Plot A. 9 inches from furrow.	Plot A. 18 inches from furrow.	Plot C. 9 inches from furrow.	Plot C. 18 inches from furrow.	Plot F. 9 inches from furrow.	Plot F. 18 inches from furrow.	Plot G. 9 inches from furrow.	Plot G. 18 inches from furrow.
0–6	Before	1.66	1.34	3.28	3.13	1.37	1.55	2.89	2.74
	After	.53	3.40	.71	13.60	.46	3.12	2.21	8.08
6–18	Before	.30	.15	.40	.53	.16	.50	.46	1.23
	After	.06	.39	.13	1.44	.15	.65	.15	2.63
18–30	Before	.06	.32	.15	.19	.08	.38	.03	.57
	After	.29	.44	.16	1.10	.18	.60	.03	1.13
30–42	Before	.11	.25	.15	.15	.09	.23	.08	.57
	After	.22	.46	.08	.59	.11	.69	.11	1.82

Depth in inches.	Sampled before or after irrigation.	Plot H. 9 inches from furrow.	Plot H. 18 inches from furrow.	Plot L. 9 inches from furrow.	Plot L. 18 inches from furrow.	Plot O. 9 inches from furrow.	Plot O. 18 inches from furrow.	Plot Q. 9 inches from furrow.	Plot Q. 18 inches from furrow.
0–6	Before	5.19	5.33	2.70	3.72	1.18	.79	1.58	3.51
	After	.81	18.41	1.09	24.44	.53	2.20	1.40	6.78
6–18	Before	.57	1.39	.25	.92	.20	.36	.22	1.55
	After	.38	1.46	.13	.81	.18	1.42	.32	1.66
18–30	Before	1.30	1.92	.16	1.29	.25	.11	.67	1.18
	After	1.09	2.56	.07	2.42	.27	.85	.74	3.54
30–42	Before	1.24	1.31	.18	.39	.23	.22	.55	.20
	After	.95	3.51	.36	3.40	.27	.53	.99	.93

In the surface 6 inches the nitrates 9 inches from the furrows are higher in all of the eight soils before irrigation, the reverse being true of the samples taken 18 inches from the furrows. As the results are consistent

throughout the entire series of eight plots, it would seem that there must have been a movement of nitrates away from the furrows, causing a reduction near the furrows and an increase 18 inches from the furrow. At a depth of 6 to 18 inches the nitrates were apparently moved more slowly; however, the amount found 9 inches from the furrows is somewhat less after irrigation in all the soils except soil Q, while at a distance of 18 inches from the furrow there is a gain in all of the soils with the exception of soil L. At a depth of 18 to 30 inches the nitric nitrogen is very low, and no consistent reduction is shown in the samples taken 9 inches from the furrow; but a consistent gain is shown in samples 18 inches from the furrow, indicating that a lateral movement has taken place at this depth. The results secured at a depth of 30 to 42 inches are very similar to those obtained for a depth of 18 to 30 inches.

During the season of 1916 extensive studies were carried out on the lateral movement of nitric nitrogen in furrow-irrigated soils. At the beginning of the irrigation season small squares were selected in each of 14 plots. Samples were drawn from these squares just before and as soon after irrigation as the moisture conditions would permit. One set of samples was taken from the bottom of the furrows, a second set about 9 inches from the furrows, and a third set about 18 inches from the furrows. The furrows are approximately 36 inches from center to center; therefore the third set of samples were drawn from a point about midway between the furrows. Each sample for analysis was made up from six borings, which were located within the square formed by four trees. The distribution of the borings within the square is shown in figure 2. The samples were drawn from the same square before and after each irrigation. The holes made in taking the first set of samples were filled in and the borings made in securing the second set of samples were located as near the first borings as practicable. As the furrows were about 6 inches deep and the samples drawn after the furrows were run

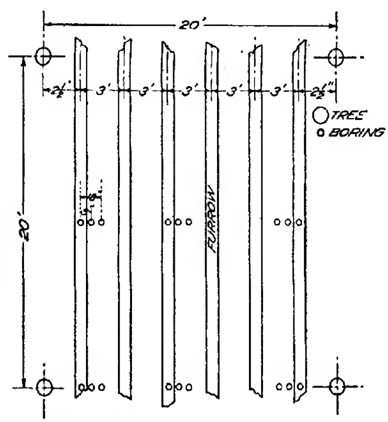

FIG. 2.—Diagram showing the location of soil-sample borings made in studying the lateral movement of nitrates in furrow-irrigated soils.

out, the results for the upper 6 inches show only the nitric nitrogen and 18 inches from furrows. Figure 3 shows the distribution of nitric nitrogen in the soil of plot A, beginning with the first irrigation and

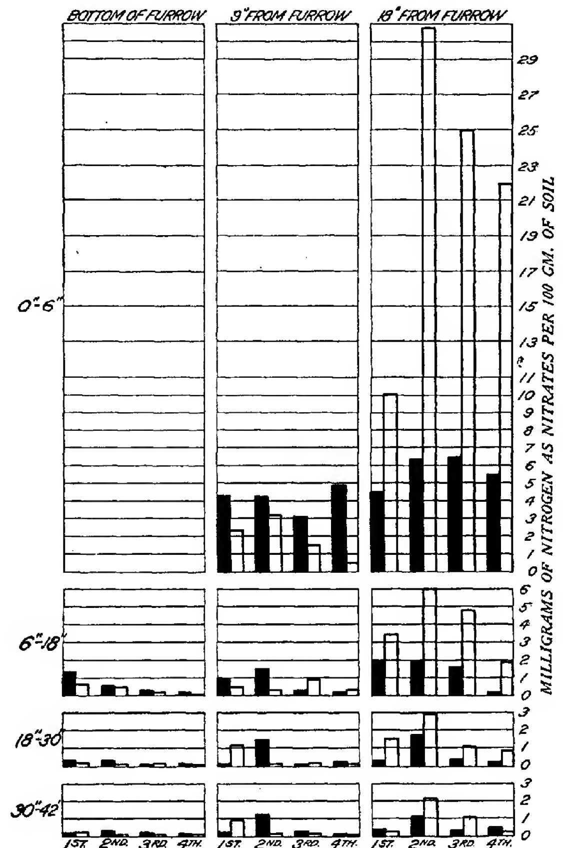

FIG. 3.—Diagram showing the distribution of nitrates in plot A before and after irrigations. Season of 1916.

continuing for four successive irrigations. The samples drawn just before the first irrigation show a rather even distribution of nitrates in this soil, which in the upper 6 inches amounts to about 4.5 mgm. After

irrigation the nitrates 9 inches from the furrow have been reduced to about 2.5 mgm., while the soil 18 inches from the furrows has increased to 10 mgm. A lateral movement has also taken place at a depth of 6 to 18 inches. The results obtained below a depth of 18 inches for the first irrigation are somewhat erratic. Samples drawn before the second irrigation indicate a more even distribution of nitric nitrogen than did the samples drawn after the first irrigation. In the upper 6 inches the frequent cultivation between irrigations is, no doubt, a factor in bringing about a more even distribution of nitrates. However, it is seen that there is apparently a more even distribution of nitric nitrogen below the cultivated zone before each irrigation than after the previous irrigation. It does not seem possible that the greater uniformity in distribution before irrigations can be due to diffusion, as the moisture in soils, when not water-soaked, is quite different from that existing in the case of liquids confined in a vessel. The soil moisture being distributed in discontinuous phases would seem to make the force of diffusion of little consequence in bringing about a more even distribution of the nitrates concentrated in zones by the lateral movement of the irrigation water. It is believed that the apparently more even distribution before an irrigation than after the last irrigation may be explained in a large measure by the lack of uniformity in the distribution of furrows from one irrigation to another. It is readily apparent that if the position of the furrows varied a few inches from one irrigation to another the samples drawn 9 inches from the new furrows might be equidistant between the old furrows, or possibly less than 9 inches from an old furrow. As the samples for analysis were made up of six borings, it seems reasonable to suppose that the results before irrigation would indicate a more even distribution of nitrates than the samples drawn after the last irrigation unless the location of the furrows were run at exactly the same point for each irrigation.

The second irrigation showed a very marked lateral movement, which was apparent even at a depth of 30 to 42 inches. Before irrigation the nitric nitrogen amounted to about 4.5 mgm. 9 inches from the furrow and 6.5 mgm. 18 inches from the furrow. After irrigation the nitric nitrogen 9 inches from the furrow was reduced to 3.2 mgm., while the amount 18 inches from the furrow was increased to 30.8 mgm. The lateral movement was also marked in the second, third, and fourth depths. The effect of the third and fourth irrigations, like the first and second, caused marked changes in the lateral distribution of the nitric nitrogen. During the fourth irrigation the supply in the upper 6 inches 9 inches from the furrow fell from 4.9 to 0.5 mgm., while the supply equidistant between the furrows rose from 5.5 to 21.9 mgm.

Plot B has received no fertilizer, and the nitrate supply was very low. However, a comparison of the nitrate content 9 inches from the furrow with that 18 inches from the furrow showed that there has apparently

been a strong lateral movement of nitrates in the surface layers, causing a variation from 0.18 to 5.85 mgm. (fig. 4).

At the beginning of the irrigation season the soil of plot C, as shown in figure 5, had a fairly uniform lateral distribution of nitric nitrogen. During the irrigation season the distribution of nitrates was very uneven in this soil.

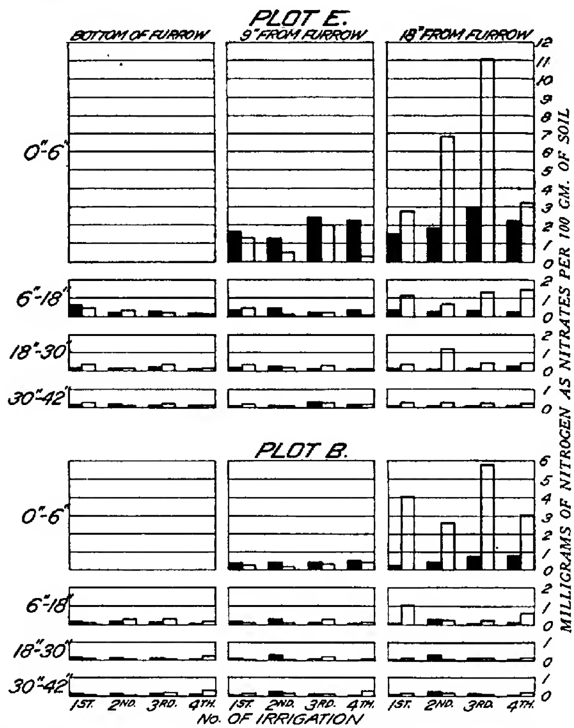

FIG. 4.—Diagram showing the distribution of nitrates in plots E and B before and after irrigations. Season of 1916.

Plot E received only one-third as much nitrogen as plot A, and it was observed that the quantity of nitrate accumulating between the furrows was much smaller. However, in the upper 6 inches the lateral movement was consistent throughout the season and showed a variation from 0.29 to 11.1 mgm. The lowest amount of nitric nitrogen found at a depth of 6 to 18 inches was 0.08 mgm., and the maximum amount was 1.45 mgm.

At a depth of 18 to 30 inches the nitrate content was very low in all cases, the maximum amount found being only 0.32 mgm.

The nitrate content of the surface 6 inches in plot F as shown in figure 6 amounted to only 1.2 mgm. at the time of the first irrigation. During

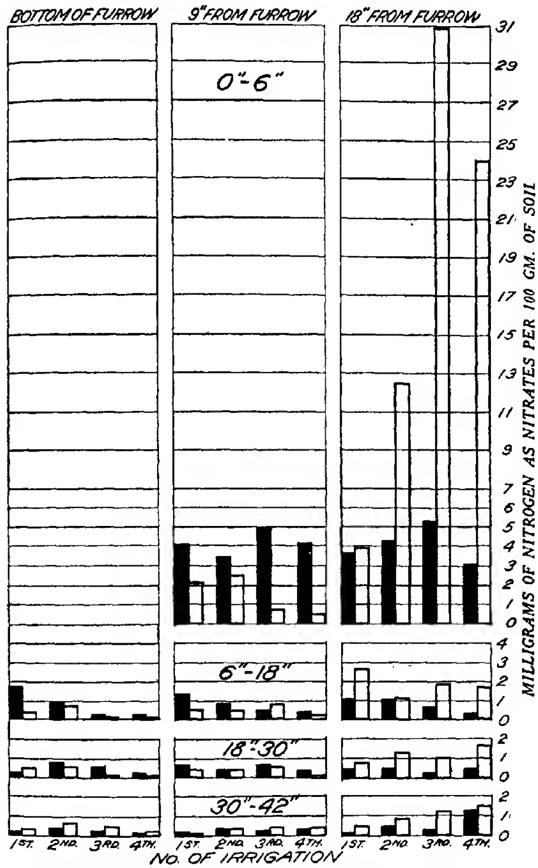

FIG. 5.—Diagram showing the distribution of nitrates in plot C before and after irrigations. Season of 1916.

the time intervening between the first and second irrigation the nitric nitrogen increased to 2.48 mgm., after which the amount remained fairly constant for the remainder of the season. The increase between the first

and second irrigation was presumably due to the nitrification of the barnyard manure, which was applied several weeks before the first irrigation. It was observed that the concentration of nitric nitrogen in the surface 6 inches of soil 18 inches from the furrow was comparatively small, considering the amount of nitric nitrogen in the soil. In this soil the highest nitrate content amounted to 6.55 mgm., which is but little higher than the highest amount secured in plot B, which received no nitrogenous fertilizers and in which the nitrate content as a whole was much lower. Notwithstanding the comparatively weak lateral movement in the surface 6 inches, the concentration of nitrates 18 inches from the lower depth was quite marked, causing a very uneven distribution of the nitrates within reach of the feeding roots.

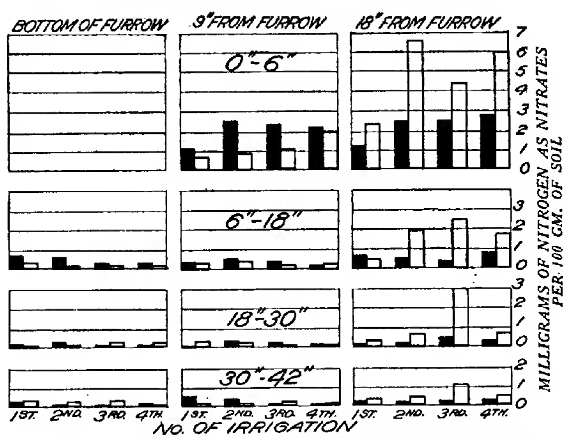

FIG. 6.—Diagram showing the distribution of nitrates in plot F before and after irrigations. Season of 1916.

Plot G shows an accumulation of nitric nitrogen 18 inches from the furrows after the second irrigation, amounting to 29.65 mgm., while the supply 9 inches from the furrow at this time amounted to only 2.56 mgm. At the lower depths the nitrate content is much smaller, and the variation is less marked. However, there is a tendency for the nitrates to move toward the point farther from the furrows, even at a depth of 30 to 42 inches (fig. 7).

At the beginning of the irrigation season the soil of plot H showed a high nitrate content in the upper layers, which amounted to 6.22 mgm. in the upper 6 inches and 3.63 mgm. at a depth of 6 to 18 inches. Before the first irrigation the nitric nitrogen in the upper 6 inches was found to be nearly the same at 9 and 18 inches from the furrow. After the third irrigation the variation was from 2.14 to 42 mgm. The distribution

of the nitric nitrogen is also extremely variable at the lower depth, but the lateral movement of the nitrates from the furrows is not as consistently shown in the soil of plot H as in some of the other soils (fig. 8).

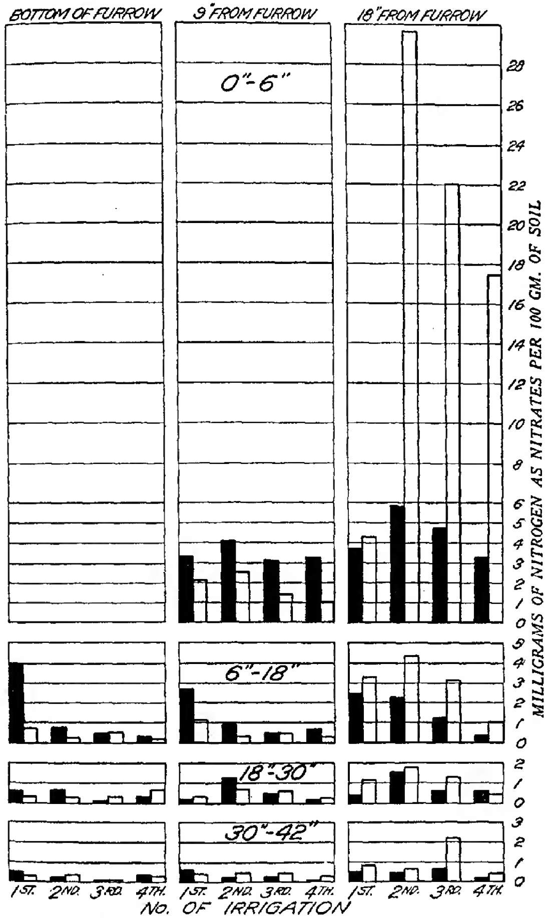

FIG. 7.—Diagram showing the distribution of nitrates in plot G before and after irrigations. Season of 1916.

The data presented in figure 9 show a strong and rather consistent lateral movement of nitric nitrogen in soil L. In the upper 6 inches the variation during the season was from 0.69 to 37.28 mgm. From 6 to 18

inches the variation was from 0.11 to 4.08 mgm. The next depth shows a variation from 0.11 to 3.75 mgm.; and even then at a depth of 30 to 42 inches the variation during the season was from 0.18 to 2.14 mgm.

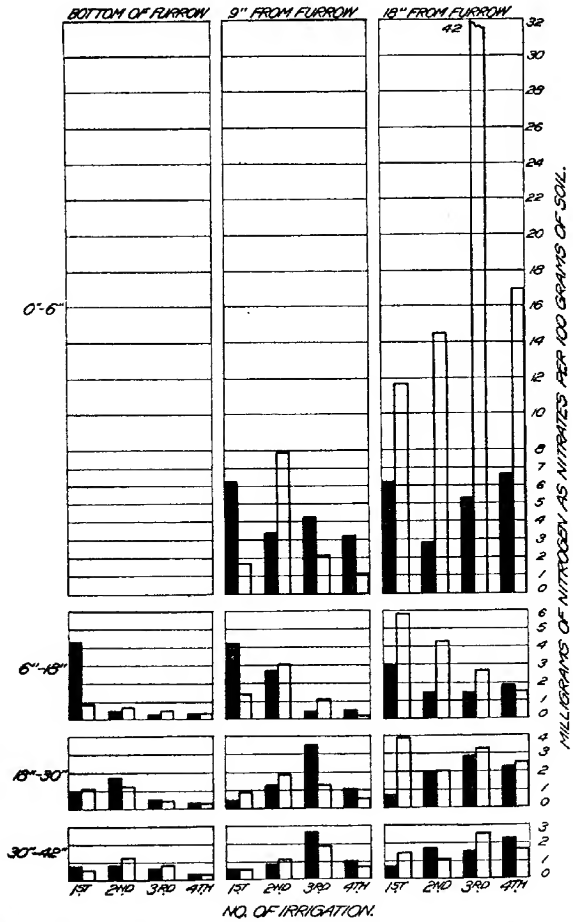

FIG. 8.—Diagram showing the distribution of nitrates in plot H before and after irrigations. Season of 1916.

Plot M has never received any nitrogenous fertilizers; consequently the nitrate content of the soil is extremely low. Even the upper 6 inches showed a nitrate content of only 0.55 mgm. at the time of the first irri-

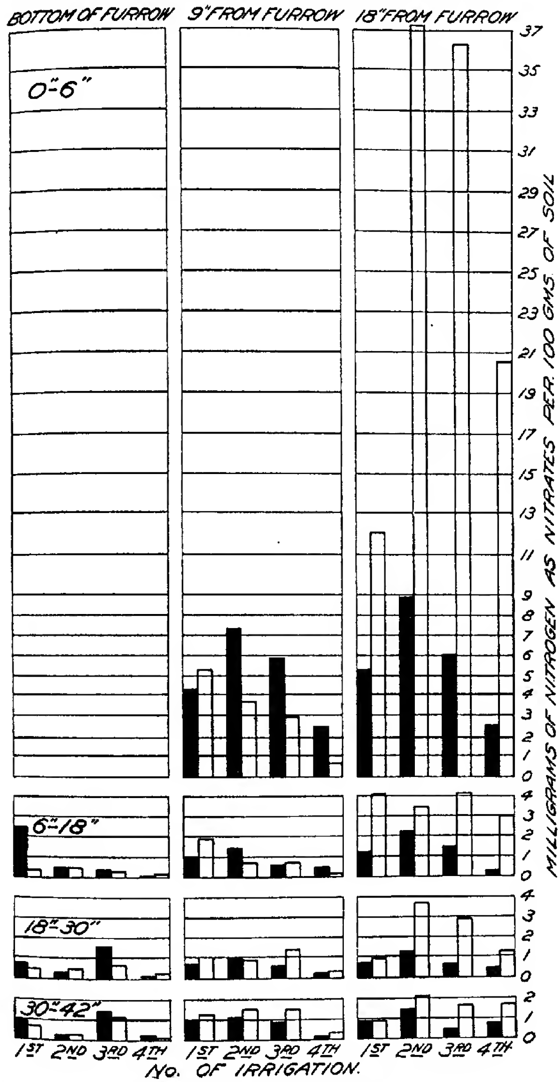

FIG. 9.—Diagram showing the distribution of nitrates in plot L before and after irrigations. Season of 1916.

gation. With this small nitrate content it would seem scarcely possible to secure high concentrations at any point as a result of the irrigation. However, after the second irrigation the nitric nitrogen in the surface 6 inches of soil 18 inches from the furrow amounted to 4.07 mgm., while 9 inches from the furrows it amounted to only 0.5 mgm. The nitrate supply below 6 inches is very low, and little or no movement can be traced to the irrigation (fig. 10).

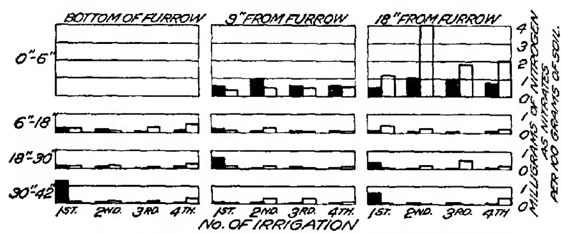

FIG. 10.—Diagram showing the distribution of nitrates in plot M before and after irrigations. Season of 1916.

The nitric nitrogen in the soil from plot O was low at the beginning of the irrigation season. The upper 6 inches showed a supply of only 0.65 mgm., while the amount of the lower depths was considerably less. Between the first and second irrigations there is a rather marked increase in the nitrate content of the upper 6 inches. This increase, like that in

FIG. 11.—Diagram showing the distribution of nitrates in plot O before and after irrigations. Season of 1916.

plot F, is presumably due to the nitrification of the manure which was applied during the early spring. The maximum amount of nitric nitrogen found in the upper 6 inches of this soil was 5.25 mgm., which indicates a very weak lateral movement. There was apparently some tendency for the nitrates to move away from the furrows in the deeper layers, but the distribution was apparently much more uniform than in the other manure plot, which was a much lighter soil (fig. 11).

At the time of the first irrigation the nitrate content of the upper 6 inches of soil Q amounted to 3.07 mgm. In this soil the maximum nitrate content of 17.81 mgm. was secured in the upper 6 inches after the third irrigation. The highest nitrate content at each depth was found at the point farthest from the furrows, while the lowest in each depth was

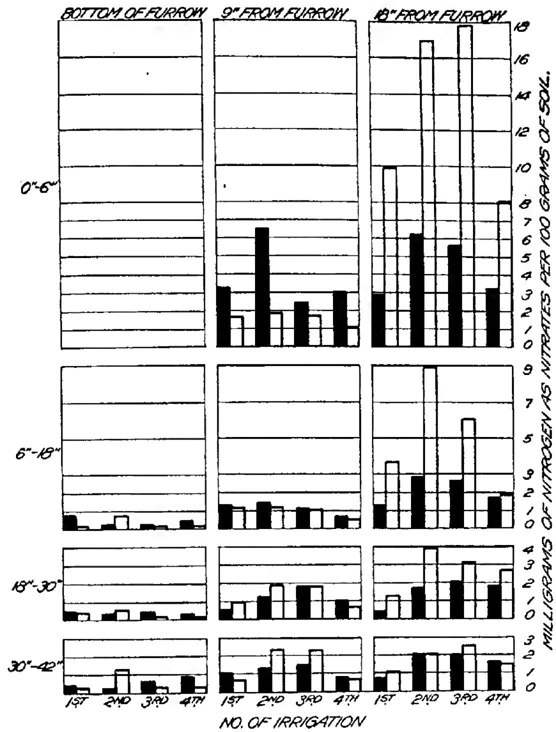

FIG. 12.—Diagram showing the distribution of nitrates in plot Q before and after irrigations. Season of 1916.

below the furrows. However, the minimum amount under the furrows was in no case less than 0.25 mgm., and the minimum amount 9 inches from the furrow was 0.56 mgm. Thus, it would seem that while the nitrate supply in this soil is somewhat uneven, there is no part of the soil which does not contain a considerable amount of available nitrogen (fig. 12).

The nitrate content of the soil in plot R, like the other soils which have received no nitrogenous fertilizers, is very low. At the time of the first irrigation the amount found in the upper 6 inches amounted to only 0.34 mgm. The maximum quantity found within reach of the roots amounted to only 0.21 mgm., and in many cases less than 0.10 mgm. was found. After the second irrigation the nitric nitrogen in the upper 6 inches 18 inches from the furrows amounted to 2.5 mgm., while only 0.29 mgm. was found 9 inches from the furrows (fig. 13).

Plot S lies immediately adjacent to plot R, and the effect of the dried blood added has evidently caused a very marked increase in the nitrate content of the soil. At the time of the first irrigation the upper 6 inches contained 6.36 mgm., the layer from 6 to 18 inches 2.19 mgm., the layer from 18 to 30 inches 1.10 mgm., and the layer from 30 to 42 inches 1.09 mgm. Thus, it is seen that at the beginning of the irrigation season there was a very satisfactory nitrate supply in this soil, and that the lateral distribution was apparently quite uniform before the first irri-

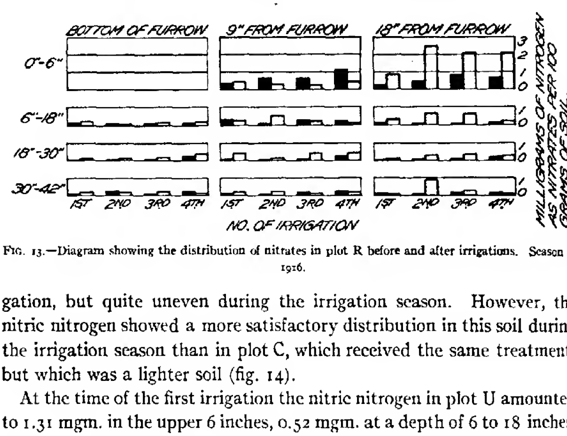

FIG. 13.—Diagram showing the distribution of nitrates in plot R before and after irrigations. Season of 1916.

gation, but quite uneven during the irrigation season. However, the nitric nitrogen showed a more satisfactory distribution in this soil during the irrigation season than in plot C, which received the same treatment, but which was a lighter soil (fig. 14).

At the time of the first irrigation the nitric nitrogen in plot U amounted to 1.31 mgm. in the upper 6 inches, 0.52 mgm. at a depth of 6 to 18 inches, and at the lower depths to less than 0.20 mgm. During the irrigation season the amount of nitric nitrogen found in the upper 6 inches varied from 0.88 to 11.8 mgm. At a depth of 6 to 18 inches the maximum amount found amounted to 3.05 mgm., while the minimum amount found at this depth was 0.25 mgm. (fig. 15).

The data presented in figures 3 to 16 show conclusively that the furrow system of irrigation causes a very uneven distribution of nitric nitrogen in soils; but as the work progressed it became apparent that samples drawn from the bottom of the furrows, 9 and 18 inches from the furrows, were not sufficient to show the maximum effect of the irrigation, as the highest concentration of nitrates did not always occur midway

between the furrows. As the highest concentration could not always be located from observation, it seemed necessary, in order to secure an accurate knowledge of the distribution between furrows, to remove all of the soil in small blocks from one furrow to another. A special soil sampler was therefore designed, which made it possible to remove a block of soil 2 by 4 inches to any depth desired. As it was evident that a very high percentage of the nitrogen accumulated in the surface layers, the soil was removed in 3-inch layers. Each block of soil 2 by 4 by 3

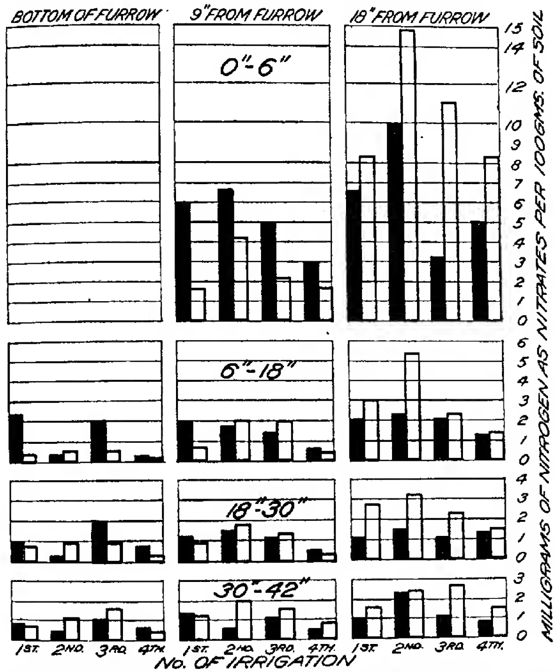

FIG. 14—Diagram showing the distribution of nitrates in plot S before and after irrigations. Season of 1916.

inches was analyzed separately. In some instances the soil below a depth of 12 to 15 inches was removed in 12-inch sections, a number of borings being made in the bottom of the trench to make up the sample for analysis.

On August 7 samples were taken from five plots in the Citrus Experiment Station grove, as shown in Table XXI. All of the soil was removed in a 2-inch strip from furrow to furrow to a depth of 12 inches in plots A, B, G, and M, and to a depth of 15 inches in plot L.

TABLE XXI.—*Distribution of nitrates at right angles to furrows, Citrus Experiment Station grove, Riverside, Cal. August 7, 1916*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Plot No.	Depth.	Boring No.									Average.
		1	2	3	4	5	6	7	8	9	
	Inches.										
A	0- 3	2.60	3.58	12.08	13.41	29.30	21.00	20.41	7.40	7.33	13.01
	3- 6	.61	.89	1.23	1.16	3.89	2.00	1.34	.64	.19	1.33
	6- 9	.57	.57	.32	.95	2.00	1.30	1.38	.43	.68	.91
	9-12	.29	.50	.88	1.79	1.51	1.02	1.48	.64	.61	.97
B	0- 3	.28	.42	1.06	1.58	1.06	.67	.32	....	....	.78
	3- 6	.18	.15	.08	.64	.18	.11	.15	....	....	.21
	6- 9	.15	.18	.08	.15	.11	.11	.18	....	....	.14
	9-12	.08	.18	.08	.11	.08	.08	.08	....	....	.10
	12-24	....	....	....	....	....	....	....	....	....	.08
	24-36	....	....	....	....	....	....	....	....	....	.15
	36-48	....	....	....	....	....	....	....	....	....	.15
G	0- 3	.43	3.58	6.66	4.35	35.01	19.61	5.47	1.41	.89	8.60
	3- 6	.40	3.96	.99	2.39	10.23	1.87	.36	.29	.15	2.29
	6- 9	.33	.36	.26	.92	3.74	2.27	.50	.19	.19	.97
	9-12	.43	.36	.36	1.27	2.04	.99	.40	.29	.29	.72
L	0- 3	2.10	11.80	23.10	67.90	21.49	4.50	2.50	1.50	.90	15.09
	3- 6	.27	1.10	1.96	3.75	6.08	5.46	.56	.28	.26	2.19
	6- 9	.24	2.00	2.10	.95	2.80	5.20	.79	.28	.24	1.62
	9-12	.25	.20	1.85	1.20	2.20	1.49	1.20	.40	.18	1.00
	12-15	.21	.21	.44	1.00	.98	.78	.60	.36	.21	.53
M	0- 3	.28	.30	4.10	4.40	1.10	.76	.49	.28	....	1.46
	3- 6	.20	.28	.56	.65	.42	.40	.28	.28	....	.38
	6- 9	.20	.56	.84	.56	.30	.48	.20	.18	....	.42
	9-12	.18	.18	.21	.28	.41	.35	.26	.24	....	.26

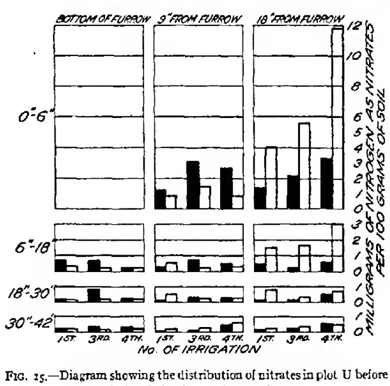

FIG. 15.—Diagram showing the distribution of nitrates in plot U before and after irrigations. Season of 1916.

In plot A it is observed that the highest amount of nitric nitrogen found in the upper 3 inches of soil was in boring 5—29.30 mgm.—while the amount found in the surface 3 inches in boring 1 amounted to only 2.60 mgm. The highest amounts found in the second and third sections were also for boring 5, which was about midway between the furrows. It is therefore apparent that the distribution of nitrates in this soil was influenced to a considerable extent by the irrigation. The column of averages for plot A shows that 80 per cent of the nitrates in the upper foot was found in the surface 3 inches, and the next highest amount was at a depth of 3 to 6 inches.

The samples from plot B were taken between furrows run at a distance of 28 inches. Only seven borings were therefore necessary to remove the

soil between the furrows. Soil B never received any fertilizer and, as shown in figure 1, it lies adjacent to soil A, which received 145.8 pounds of nitrogen per acre each year. On comparing the amount of nitric nitrogen found in plot B with that in plot A, it is seen that soil A contained about 18 times as much nitric nitrogen as soil B in the upper 3 inches. At a depth of 3 to 6 inches soil B contained only 0.21 mgm., as compared with 1.33 mgm. at the same depth in soil A. Soil B also contained a much smaller nitrate content from 6 to 12 inches than did soil A, thus showing that the fertilizer applied to soil A very greatly increased the nitrate content of the surface layers of the soil.

In the upper 3 inches of soil G the variation in nitrate content was from 0.43 mgm. in boring 1 to 35.01 mgm. in boring 5. The column of averages shows that a very high percentage of the nitrates found in the first foot of this soil was confined in the upper 6 inches, which are above the feeding roots of the tree.

The results secured with the soil in plot L were similar to those obtained in soils A and G, although the highest nitrate content was not always midway between the furrows, indicating that the lateral movement of the irrigation water took place more rapidly from one furrow than from the other.

The amount of nitrates found in the soil of plot M, like that of plot B, was low. However, the distribution of the nitrates was quite variable. The highest amounts are always found at some distance from the furrows; but, as in soil L, the maximum quantity found is not always midway between the furrows. Although no fertilizer was applied to this soil, there was a tendency for the nitrates to accumulate in the upper 3 inches, where the average amount was 1.46 mgm., as compared with 0.38 mgm. at a depth of 3 to 6 inches.

On September 12 and 13 samples were drawn from five plots in the Citrus Experiment Station grove at Arlington. The distribution of nitrates in these soils is given in Table XXII.

Plot 13 has received 22 pounds and 14 ounces of blood per tree each year for two years. The nitrate in the upper 3 inches on September 12, 1916, is shown in Table XXII. The soil removed in borings 2 and 6, which are near the furrows, contains only 3.37 and 2.28 mgm., respectively, while the soil removed in boring 4, which is farthest from the furrows, contains 40.78 mgm. A study of the column of averages is interesting, as it indicates that about 50 per cent of the nitric nitrogen found in the first 4 feet of soil is located in the upper 3 inches, which is well above the feeding roots of the tree. It also appears that the lowest nitrate supply is from 6 to 24 inches, at which depths the largest number of feeding roots are probably located.

Plot 14 lies immediately adjacent to plot 13 and was conducted as a control. The character of the soil was quite similar, and, as the samples in both plots were taken between furrows 28 inches apart, it would seem that the difference in nitrate content may be attributed to

the fertilization. On comparing the column of averages for these two plots it is seen that the nitrate content of plot 14 was small as compared with that found in plot 13. But, notwithstanding the limited supply of nitrates in this soil, it is seen that approximately 75 per cent of the nitric nitrogen found to a depth of 4 feet was confined in the upper 3 inches of soil. In plot 14 the maximum amount found at each depth was in boring 4, which was farthest from the furrows, indicating a consistent lateral movement of the nitric nitrogen.

TABLE XXII.—*Distribution of nitrates at right angles to furrows, Citrus Experiment Station grove, Arlington, Cal.*

[Results expressed as milligrams of nitrogen per 100 gms. of soil]

Plot No., material added, and sampling date.	Depth.	Boring No.								Average.
		1	2	3	4	5	6	7	8	
	Inches.									
13 (dried blood), sampled Sept. 12, 1916.	0- 3	......	3.37	27.90	40.78	11.38	2.28	......	......	17.14
	3- 6	0.64	5.22	3.61	3.19	1.20	1.69	1.27	......	2.40
	6- 9	.22	.39	1.37	1.16	.46	.43	.36	......	.63
	9-12	.29	.39	.78	1.86	.53	.36	.60	......	.69
	12-24	......	......	......	......	......	......	......	......	.43
	24-36	......	......	......	......	......	......	......	......	1.51
	36-48	......	......	......	......	......	......	......	......	1.30
14 (control), sampled Sept. 12, 1916.	0- 3	......	.99	4.77	8.51	1.44	.46	......	......	3.23
	3- 6	.29	.25	.43	.81	.25	.25	.18	......	.35
	6- 9	.11	.22	.22	.46	.11	.18	.15	......	.21
	9-12	.08	.11	.25	.46	.11	.18	.11	......	.19
	12-24	......	......	......	......	......	......	......	......	.05
	24-36	......	......	......	......	......	......	......	......	.05
	36-48	......	......	......	......	......	......	......	......	.04
26 (control), sampled Sept. 12, 1916.	0- 3	......	.59	6.94	7.78	5.26	4.81	.73	......	4.35
	3- 6	.43	.49	1.43	.89	.85	.61	.38	0.29	.67
	6- 9	.22	.28	.64	.71	.78	.71	.43	.64	.55
	9-12	.22	.33	1.77	.32	.39	.61	.50	.19	.54
	12-24	......	......	......	......	......	......	......	......	.29
	24-36	......	......	......	......	......	......	......	......	.15
	36-48	......	......	......	......	......	......	......	......	.22
25 (barley-straw mulch and nitrate of lime), sampled Sept. 13, 1916.	0- 3	......	3.23	12.12	12.76	32.00	13.10	8.62	......	13.64
	3- 6	.54	.99	.85	3.97	6.17	1.10	.71	1.06	1.92
	6- 9	.22	.64	.40	1.59	6.73	1.06	.43	.43	1.44
	9-12	.22	.29	.26	.82	4.42	1.90	.33	.19	1.05
	12-24	......	......	......	......	......	......	......	......	.43
	24-36	......	......	......	......	......	......	......	......	.43
	36-48	......	......	......	......	......	......	......	......	.12
36 (alfalfa hay), sampled Sept. 13, 1916.	0- 3	......	9.88	88.70	9.60	3.86	......	......	......	28.01
	3- 6	1.62	2.15	7.26	1.06	1.06	.75	......	......	2.31
	6- 9	1.73	.71	1.95	1.94	1.10	1.24	......	......	1.44
	9-12	1.83	.99	3.72	1.34	1.20	.78	......	......	1.64
	12-24	......	......	......	......	......	......	......	......	2.64
	24-36	......	......	......	......	......	......	......	......	2.39
	36-48	......	......	......	......	......	......	......	......	1.62

Plot 25 was kept covered with barley straw, but even under a mulch of this character it is seen that there was a large accumulation of nitric nitrogen at the surface, which varied from 3.23 to 32.0 mgm. in the upper 3 inches. The results also indicate a strong lateral movement to a depth of 12 inches. The highest nitrate content in each case was secured in boring 5, which was presumably the point at which the water met. The column of averages indicates that little nitric nitrogen has been carried below a depth of 3 feet and that at least two-thirds of the nitric nitrogen in the first 4 feet was confined to the surface 3 inches.

Plot 26 lies immediately adjacent to plot 25 and has received no fertilizer of any character during the last two years. The samples from this plot were taken between furrows 32 inches apart; and it is

observed that there is no one boring which was consistently high, but that there was an appreciable movement of nitrates away from the furrows. The nitrate supply within reach of the roots was higher in this plot than in plot 14, which was also a control. Nearly 50 per cent of the nitrates in the upper 4 feet of soil were found in the upper 3 inches.

In plot 36 the samples were taken between the furrows run at a distance of 24 inches. The nitrate content of the surface 3 inches varied from 3.86 to 88.7 mgm. The highest amount found below the surface 3 inches is 7.26 mgm. Notwithstanding the large accumulation of nitrates in the surface soil, it is seen that the nitrate supply in this soil within reach of the feeding roots was abundant. The increase at the lower depth was presumably due to the leaching down by the winter rains of the nitrates produced during the previous season.

It would seem that the fertilized plots in this grove contained enough available nitrogen above the feeding roots to supply the needs of the trees from 1½ to 3 years. Even the unfertilized soils contained more nitrogen above the feeding roots than would be removed in an average crop of fruit.

In order to determine the distribution of nitric nitrogen in soils differing in type and treatment, samples were taken in representative groves from widely separated districts. Table XXIII shows the distribution of nitrates in soils from Covina, Corona, and Lordsburg.

Table XXIII.—*Distribution of nitrates at right angles to furrows in soils at Covina, Corona, and Lordsburg, Cal.*

[Results expressed as milligrams of nitrogen per 100 gms. of soil]

Locality and sampling date.	Depth.	Boring No. 1	2	3	4	5	6	7	8	Average.
	Inches.									
Covina (sampled Aug. 9, 1916)......	0- 3	......	6.73	11.47	7.29	13.66	6.52	2.74	......	8.07
	3- 6	0.14	.74	1.86	1.69	2.18	.93	.50	0.32	1.04
	6- 9	.81	.57	.66	.90	.67	.33	.30	.29	.57
	9-12	.25	.18	.17	.45	.32	.24	.38	.22	.28
	12-15	.46	.60	.29	.60	.39	.27	.34	.25	.40
Corona (sampled Aug. 14, 1916).....	0- 3	7.95	10.89	21.88	21.18	17.96	9.56	7.57	1.09	12.26
	3- 6	.99	1.09	5.45	28.18	5.57	7.11	1.51	.43	6.25
	6- 9	.84	.67	1.37	3.75	4.59	3.40	.81	.35	1.97
	9-12	1.02	.57	.29	.88	1.02	.95	.95	.28	.74
	12-15	.56	.43	.25	.39	.67	.74	.64	.25	.49
Lordsburg, soil A (sampled Aug. 23, 1916)............	0- 3	......	.74	7.60	20.27	1.65	3.12	.39	......	5.63
	3- 6	.25	.88	.67	1.72	.53	.67	.15	.36	.65
	6- 9	.67	.50	.25	.92	.32	.18	.50	.25	.45
	9-12	.25	.15	.50	.64	.25	.25	.18	.18	.30
	12-24	......	......	......	......	......	......	......	......	1.53
	24-36	......	......	......	......	......	......	......	......	.46
Lordsburg, soil B (sampled Aug. 23, 1916)............	0- 3	......	18.94	10.75	9.84	14.88	12.29	17.54	......	14.04
	3- 6	5.82	6.34	3.09	6.65	3.16	8.69	4.42	3.75	5.24
	6- 9	1.44	1.93	1.41	1.41	1.76	2.28	1.51	.85	1.57
	9-21	......	......	......	......	......	......	......	......	.39
	21-33	......	......	......	......	......	......	......	......	.32
Lordsburg, soil C (sampled Aug. 23, 1916)............	0- 3	......	17.54	25.64	24.64	20.34	16.00	12.08	......	19.34
	3- 6	1.09	1.16	4.53	4.73	2.60	2.14	.43	.78	2.18
	6- 9	.53	.57	.78	.81	.46	.39	.46	.25	.53
	9-12	.22	.32	.32	.25	.25	.18	.18	.18	.24
	12-24	......	......	......	......	......	......	......	......	.15
	24-36	......	......	......	......	......	......	......	......	.18
	36-48	......	......	......	......	......	......	......	......	.25
Lordsburg, soil D (sampled Aug. 23, 1916)............	0- 3	......	9.21	10.68	20.90	14.74	1.30	......	......	11.37
	3- 6	.29	.60	1.70	4.10	.85	1.13	2.14	......	1.55
	6- 9	.60	.39	.32	.60	.46	.39	.32	......	.44
	9-21	......	......	......	......	......	......	......	......	1.27
	21-33	......	......	......	......	......	......	......	......	.18
	33-45	......	......	......	......	......	......	......	......	.39

The samples taken from the grove at Covina were taken between furrows which were run at a distance of 32 inches. The nitrates in the upper 3 inches varied from 2.74 mgm. in boring 7 to 13.66 mgm. in boring 5, showing that there was a lateral movement of nitric nitrogen away from the furrows. From 3 to 6 inches the nitrates varied from 0.14 mgm. in boring 1 to 2.18 mgm. in boring 5. The nitrates found below 6 inches were comparatively low in all of the samples, and the distribution does not seem to have been influenced greatly by the irrigation. In this grove the feeding roots were fully 6 inches below the surface, and a study of the column of averages shows that the bulk of the nitrates in the upper 15 inches of soil were located above the feeding roots.

The soil from Corona had a very high nitrate content, which varied from 1.09 to 21.88 mgm. in the upper 3 inches. It is observed that the highest nitrate content in the surface layers occurred about midway between the furrows. The lateral movement of nitrates was also apparent at a depth of 6 to 9 inches, but below that depth there seemed to be no movement of nitrates away from the furrows. This grove was given rather deep cultivation, which kept the feeding roots well below the surface 6 inches. In spite of the large accumulation of nitrates in the upper 6 inches the supply within reach of the roots would seem to have been sufficient for the needs of the trees. However, with a supply of nitrogen above the roots sufficient for the needs of the tree for a period of at least 18 months, it would seem that the loss of nitrogen from leaching or other causes may have been considerable.

The figures for the first three groves in the Lordsburg section, all of which were on very light soils, show a strong lateral movement only in soil A, in which the nitrates in the upper 3 inches varied from 0.39 to 20.27 mgm. In soils B and C there appeared to be very little lateral movement of nitrates, but there was a large accumulation of nitrates in the surface 6 inches. Because of the very light character of these soils, all the groves are cultivated deeply, and the nitrates which accumulate in the upper 6 inches of soil can be of little use to the tree during the present season. In soil C the nitric nitrogen in the upper 3 inches averaged 19.34 mgm., while the average nitrate supply within reach of the roots was only 0.27 mgm. Such a distribution in these extremely light soils must lead to very heavy losses of nitrogen from leaching. In soil D, which is a heavy clay, the highest nitrate content was found in boring 4, which was located about midway between the furrows. In this soil there were a few feeding roots within 4 inches of the surface, but even if we consider all the nitrates available except those confined in the surface 3 inches, there was approximately two-thirds of the nitric nitrogen which was unavailable.

The distribution of nitrates in soils at Orange, Anaheim, and Whittier is shown in Table XXIV. In the grove at Orange the highest nitrate content for each section was found in boring 4, which indicates that irrigation water caused a somewhat uneven lateral distribution of nitrates.

About 90 per cent of the nitrates in the surface foot of soil were located in the upper 6 inches, in which no feeding roots could be found.

TABLE XXIV.—*Distribution of nitrates at right angles to furrows in soils at Orange, Anaheim, and Whittier, Cal.*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Locality and date of sampling.	Depth.	Boring No. 1	2	3	4	5	6	7	8	Average.
	Inches.									
Orange (sampled Aug. 29, 1916)	0- 3	....	10.02	19.71	29.58	9.14	....	....	....	17.11
	3- 6	1.44	1.97	3.26	7.81	1.86	0.78	....	....	2.85
	6- 9	.81	1.06	1.02	2.00	1.02	1.09	....	....	1.17
	9-12	.67	.67	.46	1.20	1.13	.99	....	....	.85
Anaheim (sampled Aug. 29, 1916)	0- 3	....	.85	2.98	7.99	1.16	....	....	....	3.24
	3- 6	.43	.43	3.19	1.72	.32	.39	....	....	1.08
	6- 9	.60	.25	1.27	.74	.39	.29	....	....	.59
	9-12	.22	.29	.71	.32	.32	.94	....	....	.31
Whittier (sampled Aug. 30, 1916)	0- 3	....	18.97	19.39	36.08	9.67	24.04	9.49	....	19.61
	3- 6	1.58	1.51	8.89	6.79	8.64	2.72	1.87	3.47	4.43
	6- 9	1.29	1.87	2.19	3.76	3.69	2.34	1.04	.82	2.12
	9-12	3.30	3.44	6.96	5.61	3.39	1.67	.66	.32	3.17
	12-24	....	....	....	....	....	....	....	....	4.17
	24-36	....	....	....	....	....	....	....	....	5.15
	36-48	....	....	....	....	....	....	....	....	4.14
	48-60	....	....	....	....	....	....	....	....	5.40

The Anaheim soil, although comparatively low in nitric nitrogen, showed a very uneven distribution, which was apparently due to the lateral movement caused by the irrigation water.

The Whittier soil was unusually rich in nitric nitrogen, and, while it showed a very large accumulation at the surface, the lateral distribution was more uniform than in most furrow-irrigated soils. It would seem that several crops of fruit must be grown before the nitrates in this soil can be utilized, and in the meantime the irrigation and rainfall will probably have carried away much of the supply, causing considerable loss.

During the month of August samples were taken from groves at Redlands, Highland, and Rialto. The distribution of nitrates in these soils is shown in Table XXV. The two soils from the Redlands district show that a large percentage of the nitric nitrogen which they contain is found in the upper 3 inches of soil, and also that the lateral distribution is very uneven.

It was apparent that the available nitrogen in grove A was not sufficient for the needs of the trees, as they showed the characteristic nitrogen-starved appearance. However, if the nitrates which have accumulated in the surface 3 inches of this soil could be brought within reach of the roots, the nitrogen supply would probably be sufficient for the production of a fair crop of fruit.

The trees in grove B seemed to get sufficient nitrogen, as the foliage was in good condition and they bore a good crop of fruit. On comparing the nitrate content of soils A and B below the upper 6 inches, it is seen that the latter contains about twice as much nitric nitrogen as the former.

Notwithstanding the fact that considerable quantities of commercial nitrogen have been added during the season, the nitrate content of the

Highland soil was found to be very low. This grove bore a cover crop of *Melilotus alba* at the time the samples were taken, and it is believed that the low nitrate content is due to the growth of this crop. A number of soils on which melilotus was growing have been analyzed for nitrates from time to time during the growth of the crop, and it has been found that the growth of melilotus invariably reduces the nitrate content of the soil very materially.

TABLE XXV.—*Distribution of nitrates at right angles to furrows in soils at Redlands, Highland, and Rialto, Cal.*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Locality and date of sampling.	Depth.	Boring No.								Average.
		1	2	3	4	5	6	7	8	
	Inches.									
Redlands, soil A (sampled Aug. 22, 1916)	0- 3	......	0.74	4.94	14.18	4.24	4.17	1.09	......	4.89
	3- 6	0.18	.32	1.06	2.18	.88	.32	.18	0.25	.67
	6- 9	.18	.11	.11	.46	.25	.08	.18	.08	.18
	9-12	.11	.11	.25	.11	.18	.15	.05	.11	.14
	12-24	......	......	......	......	......	......	......	......	.11
	24-36	......	......	......	......	......	......	......	......	.18
	36-48	......	......	......	......	......	......	......	......	.11
Redlands, soil B (sampled Aug. 22, 1916)	0- 3	......	1.44	8.58	4.92	9.86	3.33	.57	......	4.79
	3- 6	.39	.36	.50	2.63	.53	.39	.15	......	.71
	6- 9	.46	.32	.88	.67	.39	.25	.22	......	.46
	9-12	.22	.65	.18	.15	.22	.15	.11	......	.24
Highland (sampled Aug. 1, 1916)	0- 3	......	.19	5.50	1.16	.18	.11	.13	......	1.21
	3- 6	.15	3.30	.18	.11	.15	.11	.36	.11	.56
	6- 9	.15	.11	.11	.15	.08	.04	.11	.04	.10
	9-12	.11	.11	.11	.08	.11	.11	.08	.08	.10
	12-15	.03	.01	.01	.01	.08	.11	.03	.01	.04
Rialto (sampled Aug. 22, 1916)	0- 3	......	3.61	9.84	12.92	6.62	2.91	1.02	......	6.15
	3- 6	.60	.95	13.20	2.77	5.50	2.98	.53	.53	3.38
	6- 9	.18	.18	.67	.53	.53	.53	.11	.29	.38
	9-12	.11	.32	.74	.60	.50	.32	.18	.18	.37

The Rialto soil was extremely sandy at the surface, and below a depth of 12 inches it was so filled with coarse gravel and rock as to make sampling almost impossible. About 92 per cent of the nitrogen in the surface foot of this soil is found in the upper 6 inches, in which no feeding roots could be located. It would therefore seem that most of the nitric nitrogen in this soil can be of no value until carried down within reach of the roots. The very gravelly nature of this soil would seem to make it readily subject to leaching, and it is probable that the nitrates which have accumulated at the surface during the irrigation season will be carried far beyond the reach of the roots during the rainy season.

FORMATION OF NITER SPOTS IN CITRUS SOILS

The accumulation of nitrates in surface spots in western soils was first observed by Hilgard (5), who attributed their formation to a rapid nitrification of the organic matter. Regarding the effect of rainfall on the accumulation of nitrates Hilgard wrote as follows (p. 68):

> Of course it is only in arid climates that the accumulation of nitrates can usually occur; for in the region of summer rains the nitrates formed during the warm season will inevitably be washed into the subdrainage, unless restrained by absorption by the roots of vegetation.

Some years later Headden (2) called attention to the occurrence of "niter spots" in Colorado soils. The occurrence of the high nitrates he attributed to the fixation of atmospheric nitrogen by nonsymbiotic bacteria. This view has been further amplified by Headden (3, 4) and also by Sackett (9). In 1910 Stewart (11) called attention to the occurrence of nitrate salts in the country rock adjacent to the "niter spot" areas. These observations led to further studies on the nitrate content of the country rock by Stewart and Peterson (12, 13, 14). As a result of their studies these authors maintain that the "niter spots" are the direct result of the leaching of the nitrates out of the preexisting deposits in the country rock and of being locally concentrated by seepage.

The data presented above show conclusively that the nitric nitrogen in furrow-irrigated soils is carried laterally from the irrigation furrows, causing a concentration of nitrates at the point at which the irrigation water meets between the furrows. If the surface soil becomes thoroughly moistened, as it frequently does during an irrigation, very rapid evaporation will occur between the moistening of the soil and the harrowing. If the lateral movement of the irrigation water is sufficient to cause a concentration of nitrates in zones, such as shown above, it would seem that the subsequent evaporation of water from the soil in which the nitrates are highest would cause a marked concentration at the immediate surface, and thus there would be formed a "niter spot" or streak, which would occupy that portion of the soil in which the nitrates are concentrated during the irrigation. Niter streaks can be readily observed in many groves if examined at the proper time after irrigation. They have a characteristic brownish appearance which varies from a light brown to a brownish black. The color probably depends upon a number of factors, among which the following seem to be important: The amount of calcium nitrate, the moisture content, soluble organic matter, and the presence of other soluble salts. Where the nitrates are associated with large quantities of alkali salts, a brownish crust is frequently formed on drying; but when the nitrates predominate, the streak or spot is only readily seen when the surface soil contains a considerable quantity of moisture. After the soil has dried and the niter streaks are scarcely visible during the heat of the day, the color may reappear during the night if the weather is foggy. This phenomenon seems to point strongly to the deliquescent character of the calcium nitrate as an important factor in producing the brown coloration. The importance of deliquescent salts in this regard is also suggested by the action of calcium chlorid, which produces a surface color so similar to that produced by the calcium nitrate that the writer has been unable to distinguish one from the other. When the nitric nitrogen in the spot amounts to 1 per cent or more, the deliquescent character of the salt seems to attract and hold small globules of water which glisten in the sunlight, giving the small spot in which the calcium nitrate has concentrated a silvery appearance. During hot, dry

weather the globules of water soon disappear; but if the weather is cool and humid the droplets may be retained for one or two days.

The samples for analyses were taken by scooping up a thin layer of soil from the brown spots two or three days after the irrigation water was turned off, but before the surface was disturbed by harrowing. The

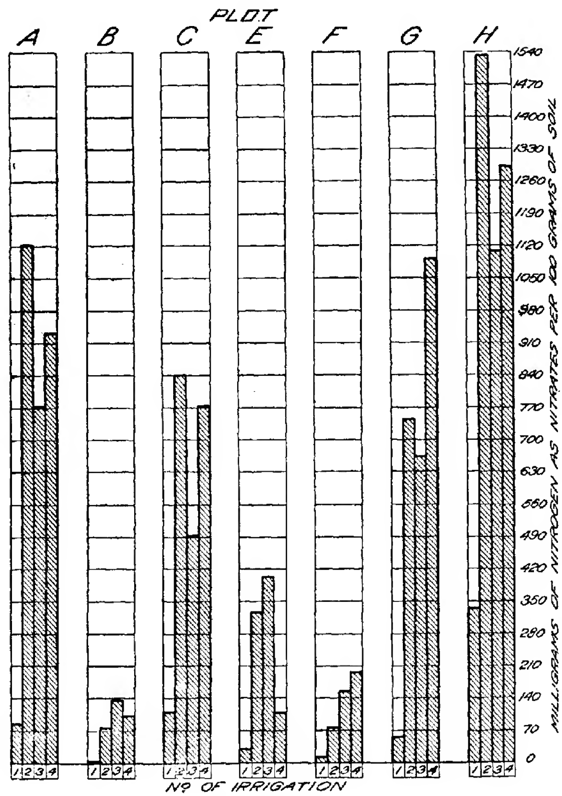

FIG. 16.—Diagram showing the nitrate content of the niter spots in furrow-irrigated soils. Season of 1916.

amount of nitric nitrogen found in the niter spots or streaks after irrigation are shown in figures 16 and 17.

The samples taken after the first irrigation show only a light accumulation of nitrates in the brown spots. At this time the brownish color characteristic of the niter spot was not abundant in any of the plots,

and in most cases the spots or streaks could be located only with difficulty. The lack of characteristic niter spots in the soil following the first irrigation is, no doubt, due to the fact that the nitrates which had accumulated at the surface during the previous season had been leached down to a considerable depth by the winter rains; and, as the new application was plowed down, there was little nitrate in the surface soil at the time of the first irrigation. The spring plowing also broke up the plowsole formed during the previous season, so that the irrigation water was not interrupted in its downward movement, and there was consequently a slower lateral movement of the water in the surface

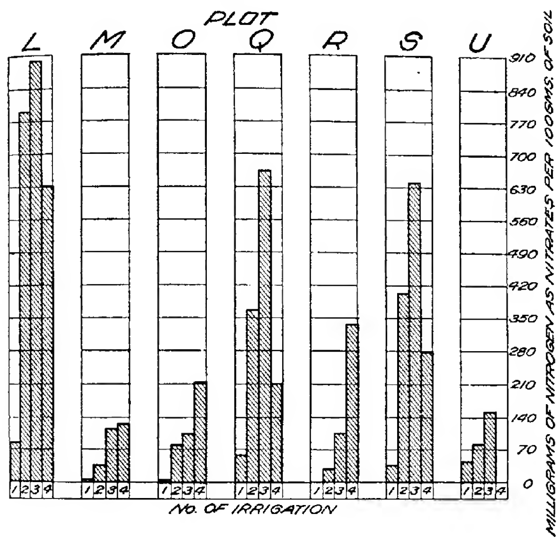

FIG. 17.—Diagram showing the nitrate content of the niter spots in furrow-irrigated soils. Season of 1916.

soil. The evaporation of moisture from the soil is also somewhat slower at this time than at the time of the later irrigations.

Following the second irrigation, niter streaks and spots were abundant in soils A, C, G, H, and L; and analyses of scrapings from these spots showed them to be very rich in nitrates. The scrapings from soil H at this time contained 1.54 per cent of nitrogen as nitrates, and soil A 1.12 per cent.

Plots B, M, and R, which have not received any nitrogenous fertilizer; plots F and O, which have received manure; plot E, which has received only a light application of nitrogen in bone meal; and plot U, which has received manure and a cover crop, show a comparatively small

amount of nitric nitrogen in the surface scrapings. It may also be stated that those plots which showed a low nitrate content in the scrapings also showed only a few niter spots, which were a light brownish color and could scarcely be distinguished after the surface soil began to dry.

After the third irrigation the nitric nitrogen found in the scrapings from the brown spots was somewhat less than after the second irrigation in plots A, C, G, and H, but was greater in all the other plots. It is seen that the nitrates in the unfertilized, lightly fertilized, and manured plots remain low as compared with those which have received large applications of nitrogen in commercial fertilizers.

After the fourth irrigation the scrapings from plots C, F, G, M, O, R, and U were higher than after any previous irrigation; but in plots E, Q, and S the amount found is much less than during the second or third irrigation. Such irregularities are to be expected, as the quantity of nitrates in the niter spots depends upon so many variable factors, such as the physical character of the soil, length of irrigation period, rapidity with which water moves laterally in the soil, rate of evaporation, length of time between irrigation and sampling, distribution of nitrates in soil at the time irrigation is started, etc.

After the consideration of only the last three irrigations it was found that the average nitrate content of the scrapings for the five plots of light soil which have received heavy applications of commercial fertilizers amounted to 0.92 per cent of nitrogen. The average nitrate content of the scrapings from the two heavy soils receiving heavy applications of commercial fertilizers was only 0.43 per cent of nitrogen. It would therefore seem that surface spots high in nitrates are less likely to be formed in heavy than in light soils, especially if the soils are underlain by a rather impervious plowsole.

The amount of nitric nitrogen found in the scrapings from plots F, O, and U is in striking contrast to the amount found in soils receiving the same or a smaller amount of nitrogen in commercial fertilizers. The average nitrate content of the scrapings from these three plots for the last three irrigations is only 0.14 per cent, which is less than one-sixth of the amount found in the light soils receiving nitrogen in commercial fertilizers.

The surface scrapings from plots B, M, and R, which have not received any nitrogen, contain an average of 0.09 per cent of nitrogen for the last three irrigations, which is but little less than the average amount found in the three plots receiving organic matter, but which is less than 10 per cent of the amount found in the scrapings from the light soils which have received 145.8 pounds of nitrogen in commercial fertilizers.

The data presented above fail to indicate that the formation of niter spots in these soils is dependent upon the processes of nitrogen fixation

or nitrification. The soils are very poor in both organic matter and total nitrogen, and the quantity of nitric nitrogen found in the control plots shows that the nitrification of the organic matter takes place very slowly. Furthermore, if the nitrogen-fixing or nitrifying bacteria were responsible for the production of the niter spots in these soils, it would seem that the niter spots in the soils receiving applications of active organic matter would be higher in nitrates than the soils to which no organic matter was applied. It is seen that this is not the case.

Inasmuch as the higher ground surrounding the experimental field is dry land and the water table is far below the zone which would make it possible for the water to move to the surface by capillary action, it would seem that the nitrate content of the soils can not be influenced by deposits of nitrates occurring in the country rock.

The formation of niter spots or streaks in Citrus soils is so definitely correlated with the fertilization and furrow system of irrigation that it would seem that there can be no doubt of the accuracy in the interpretation of the forces responsible for their formation in these soils.

DISTRIBUTION OF NITRATES IN SOILS IRRIGATED BY AN OVERHEAD SYSTEM OF IRRIGATION

During the season of 1915 a number of samples were drawn from a grove at Covina which is irrigated by an overhead system.

A portion of the grove received a mulch of bean straw, while another part remained unmulched. On July 14, as shown in Table XXVI, the highest nitrate content of the unmulched soil was at a depth of 6 to 18 inches, while the mulched soil showed the highest nitrate content at a depth of 18 to 30 inches. The mulch applied to this soil had presumably prevented rapid evaporation from the soil, and the water had therefore penetrated the soil to a greater depth than in the unmulched soil, thus carrying the nitrates somewhat deeper. Another set of samples was taken from this grove on August 2. In the meantime the grove had been given a light irrigation amounting to approximately one-half inch of water. In the overhead system of irrigation used in this grove the irrigation pipes are placed over every third row of trees. The middle farthest away from the pipes usually received less water than the middles on either side of the row above which the pipes are placed. The samples taken on July 14 were from the dry middles, and the nitric nitrogen in the unmulched soil, as stated above, had apparently not been carried below a depth of 18 inches. The samples taken from the wet middle on August 2 showed the highest nitrate content at a depth of 18 to 30 inches. Since the quantity of water added between the samplings was too small to effect the distribution of the nitrates, it would seem that the heavier irrigation given the soil near the irrigation pipe had caused a downward movement of the nitrates below 18 inches, while the lighter

irrigation given the middles farthest from the pipes left the nitrates in the upper 18 inches of soil. However, as only one set of samples was taken on each date the results may be due in part, or entirely, to a lack of uniformity in distribution.

TABLE XXVI.—*Distribution of nitrates in soils at Covina, Cal., irrigated by an overhead system of irrigation. Season of 1915*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Depth.	July 14.		Aug. 2.		Oct. 28.		Nov. 20.
	No mulch; dry middle.	Mulch; dry middle.	No mulch; wet middle.	Mulch; dry middle.	Mulch; dry middle.	No mulch; wet middle.	No mulch; wet middle.
Inches.							
0– 6	2.14	2.94	1.81	4.69	2.68	1.01	0.63
6–18	4.41	2.08	1.15	3.43	2.68	.81	.70
18–30	.21	3.43	4.03	1.33	2.68	1.30	.70
30–42	.12	.25	.28	.28	.98	1.16	.91
42–54							.98
54–66							1.02
66–78							1.54

During the latter part of the irrigation season the grove received heavier applications of water, amounting to approximately 4 inches on August 10, 5.4 inches on September 24, and 2.8 inches on October 20. A comparison of the distribution of the nitrates in the wet and the dry middle of the mulched soil on August 2 and October 28 shows that the influence of the larger application of water is clearly apparent. In the dry middle on August 2 the bulk of the nitric nitrogen was found in the upper 18 inches of soil, while it is evenly distributed in the dry middle on October 28 to a depth of 30 inches. Samples drawn from the unmulched portion of the grove on October 28 showed a nitrate content so much below the amount found on August 2 that it was thought advisable to draw samples from the deeper layers; consequently, on November 20, samples were taken to a depth of 78 inches. In these samples the highest nitrate content was found in the soil drawn from a depth of 66 to 78 inches, thus indicating that the nitrates had been carried to a depth of several feet by the irrigation water applied during the latter part of the summer.

During the season of 1916 a large number of samples were taken from the same grove at Covina on August 9, August 30, and September 2. The soil samples were taken by driving a rectangular tube (2 by 4 by 18 inches) into the soil to a depth of 3 inches, thus removing a block of soil 2 by 4 by 3 inches.

This method of sampling proved quite satisfactory when the moisture content of the soil was sufficient to cause the soil to pack into the tube so that the exact block desired could be removed. When the soil was light in character and the moisture content low, it was necessary to drive the

sampling tube to the desired depth and then drive under a thin iron plate to prevent the soil from falling out as the tube was removed.

On August 9 five successive sets of 12 samples each were drawn from a strip of soil 2 inches wide, 48 inches long, and 15 inches deep. The nitric nitrogen as determined in each sample is shown in Table XXVII. The upper 3 inches of soil showed an average nitrate content of 0.70 mgm. In the second 3-inch section the average is only 0.19 mgm., with the variation in individual samples from 0.08 to 0.25 mgm. The soil at a depth of 6 to 9 inches shows an average nitrate content of only 0.14 mgm., with a variation in individual samples from 0.05 to 0.29 mgm. The fourth and fifth sections show a higher nitrate content than the second or third.

TABLE XXVII.—*Distribution of nitrates in soils at Covina, Cal., irrigated by an overhead system of irrigation. Season of 1916*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Date of sampling.	Depth.	Boring No.												Average.
		1	2	3	4	5	6	7	8	9	10	11	12	
	Inches.													
Aug. 9	0–3	0.64	0.71	0.71	0.50	0.92	0.64	0.64	0.20	0.78	0.57	0.57	0.50	0.70
	3–6	.19	.15	.15	.22	.08	.25	.22	.15	.22	.19	.22	.22	.19
	6–9	.05	.12	.15	.12	.15	.15	.15	.12	.08	.29	.15	.15	.14
	9–12	.22	.15	.29	.29	.36	.22	.26	.29	.15	.15	.15	.15	.22
	12–15	.19	.26	.22	.29	.29	.22	.29	.26	.19	.29	.29	.22	.25
Aug. 30 (before irrigation)	0–3	1.16	1.37	1.30	1.30	.74	.67	.88	.88	.95	1.06	.92	.88	1.01
	3–6	.36	.22	.22	.25	.39	.39	.39	.25	.29	.53	.25	.22	.31
	6–9	.32	.25	.18	.22	.22	.39	.74	.36	.36	.32	.22	.18	.31
	9–12	.15	.15	.15	.15	.25	.32	.46	.22	.39	.25	.11	.15	.23
	12–24	......	......	......	......	......	......	......	......	......	......	......	......	.15
	24–36	......	......	......	......	......	......	......	......	......	......	......	......	.18
	36–48	......	......	......	......	......	......	......	......	......	......	......	......	.32
Sept. 2 (after irrigation)	0–3	.43	.39	.53	.60	.53	.60	.57	.26	1.02	.39	......	......	.55
	3–6	.36	1.16	.95	.46	.64	.29	.39	.46	.39	.50	......	......	.56
	6–9	.36	.29	.53	.67	.74	.95	.67	.60	.46	.46	......	......	.57
	9–12	.46	.50	.64	1.44	.95	1.13	.60	.39	.81	.57	......	......	.75
	12–24	......	......	......	......	......	......	......	......	......	......	......	......	.92
	24–36	......	......	......	......	......	......	......	......	......	......	......	......	.32
	36–48	......	......	......	......	......	......	......	......	......	......	......	......	.18
	48–60	......	......	......	......	......	......	......	......	......	......	......	......	.08

In this series of samples it is seen that the lateral distribution of the nitrates is quite uniform, but that there is some tendency for the nitrate to accumulate in the surface 3 inches even under an overhead system of irrigation.

In order to study more exactly the effect of overhead irrigation on the distribution of nitric nitrogen, two additional sets of samples were taken, one on August 30 just before the irrigation and the other on September 2 after an application of about 3 inches of water. On August 30 the average nitric-nitrogen content in the upper 3 inches was 1.01 mgm., which was more than the total amount found in the next three sections. On September 2 the highest nitrate content was found at a depth of 12 to 24 inches, while the surface 3 inches contained the smallest amount found in the upper 2 feet. The figures presented in Tables XXVI and XXVII would seem to leave little doubt that the overhead irrigation gives a much better distribution of nitric nitrogen than can be secured under the

furrow system. Under the overhead system it would seem that the nitrates which are formed or carried above the feeding roots by capillary action between irrigations may be leached down within reach of the roots with every application of water. On the other hand, the results secured during the season of 1915 indicate that much nitric nitrogen may be carried below the reach of the roots if too much water is applied.

DISTRIBUTION OF NITRIC NITROGEN IN BASIN-IRRIGATED SOILS

In basin irrigation the field is laid off into compartments, or checks, wholly surrounded by levees, with a tree in the center of each. The water is admitted at the upper end; and, if the basin is properly constructed, the water spreads uniformly over the bottom of the compartment, or basin. Under this system of irrigation there is less opportunity for a lateral movement of the water, such as takes place under the furrow system, in which the water is applied in small streams several feet apart.

The distribution of nitrates in basin-irrigated soils was determined by selecting a strip of soil 2 inches in width and from 40 to 48 inches in length and removing small blocks of soil having a dimension of 2 by 4 by 3 inches until all the soil was removed to a depth of 12 or 15 inches. The nitric nitrogen in each block of soil was determined separately. In three of the basins studied a large number of borings were made in the bottom of the trench in foot-sections to a depth of 48 inches, and the average nitrate content of each 12-inch section determined. The distribution of nitrates in basin-irrigated and mulched soils is shown in Table XXVIII.

TABLE XXVIII.—*Distribution of nitrates in basin-irrigated soils*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Locality and date of sampling.	Mulch.	Depth.	1	2	3	4	5	6	7	8	9	10	11	12	Average.
		Inches.													
Whittier, Aug. 30, 1916.	Bean straw....	0- 3	1.76	1.62	2.35	2.98	3.85	3.97	3.97	4.02	4.35	4.12	....	....	3.30
		3- 6	1.16	1.41	1.34	1.34	.88	1.37	1.65	1.72	2.00	2.35	....	....	1.52
		6- 9	1.51	2.00	2.25	1.16	.57	.81	.74	3.33	1.23	1.62	....	....	1.52
		9-12	1.58	1.76	3.05	2.25	.74	.60	.99	.60	.46	.74	....	....	1.28
		12-24	....	....	....	....	....	....	....	....	....	....	....	....	3.71
		24-36	....	....	....	....	....	....	....	....	....	....	....	....	2.63
		36-48	....	....	....	....	....	....	....	....	....	....	....	....	2.25
Plot 4. Citrus Experiment Station grove, Arlington, Sept. 12, 1916.	Alfalfa hay....	0- 3	1.97	2.35	3.77	3.44	3.54	2.97	3.82	3.86	3.65	4.42	4.56	3.44	3.48
		3- 6	1.02	1.06	1.41	2.00	2.35	2.77	2.25	3.16	3.26	2.49	3.25	2.07	2.26
		6- 9	.67	1.23	1.58	2.00	2.42	3.12	2.49	2.46	3.72	3.40	2.67	2.81	2.38
		9-12	1.30	1.37	1.72	1.51	2.49	3.19	2.63	2.21	3.51	3.12	3.74	2.56	2.45
		12-24	....	....	....	....	....	....	....	....	....	....	....	....	3.93
		24-36	....	....	....	....	....	....	....	....	....	....	....	....	1.55
		36-48	....	....	....	....	....	....	....	....	....	....	....	....	1.65
Plot 27. Citrus Experiment Station grove, Arlington, Sept. 12, 1916.	Barley straw..	0- 3	1.37	.71	.88	.95	.81	1.16	.53	.50	.67	.64	.50	.60	.78
		3- 6	.46	.25	.32	.39	.25	.25	.29	.29	.25	.32	.25	.25	.30
		6- 9	.46	2.00	.25	.46	.15	.17	.16	.11	.15	.18	.11	.18	.36
		9-12	.25	.39	.15	.15	.04	.15	.11	.11	.11	.15	.11	.11	.15
		12-24	....	....	....	....	....	....	....	....	....	....	....	....	.15
		24-36	....	....	....	....	....	....	....	....	....	....	....	....	.29
		36-48	....	....	....	....	....	....	....	....	....	....	....	....	.57
Riverside, July 27, 1916.	Alfalfa hay....	0- 3	.32	.32	.32	.32	.25	.29	.32	.39	.29	.39	.29	.32	.32
		3- 6	.18	.15	.11	.11	.11	.15	.39	.18	.11	.11	.15	.11	.15
		6- 9	.11	.08	.04	.08	.11	.08	.11	.11	.11	.11	.08	.15	.10
		9-12	.04	.04	.18	.11	.04	.08	.08	.11	.18	.11	.25	.11	.11
		12-15	.08	.08	.11	.11	.11	.08	.08	.08	.04	.04	.08	.04	.08
Highgrove, July 27, 1916.	...do.........	0- 3	1.09	1.02	1.23	1.06	1.09	.88	1.06	.96	.53	.39	.53	.46	.56
		3- 6	.60	.60	.81	.67	.53	.46	.39	.39	.32	.32	.32	.39	.48
		6- 9	.46	.39	.32	.39	.39	.39	.25	.32	.25	.32	.29	.39	.35
		9-12	.46	.46	.46	.53	.50	.60	.46	.32	.32	.32	.25	.60	.44
		12-15	.39	.32	.39	.39	.32	.32	.25	.25	.25	.25	.32	.32	.32

The basin at Whittier mulched with bean straw contains an abundance of nitric nitrogen, which is less evenly distributed than might be expected under this system of irrigation. In the first two sections there is a tendency for the nitrates to increase from boring 1 to boring 10. The uneven distribution is believed to be due to the fact that the bottom of the basin was about 3 inches lower under boring 1 than under boring 10. The low spots in the basin not only receive the greatest amount of water, but are covered by the heaviest mulch. The evaporation of water from a soil takes place most rapidly from the highest points if the capillary action is not interrupted. Furthermore, the mulch is thinnest on the high ground; therefore the concentration of nitrates would naturally occur at these points. However, the distribution of the nitrates is much better than the distribution found in the adjacent furrow-irrigated soil (see Table XXIV). In the basin-irrigated soil only about 7.7 per cent of the nitrogen in the first 4 feet is found in the upper 3 inches of soil, while in the adjacent furrow-irrigated soil about 24 per cent of the nitric nitrogen in the first 4 feet is found in the upper 3 inches.

The basin at Arlington mulched with alfalfa hay shows a very satisfactory distribution of nitrates. In the upper 3 inches the variation is from 1.97 to 4.56 mgm. The second section shows a variation from 1.02 to 3.25 mgm. In the third section the variation is from 0.67 to 3.72 mgm. The next section shows a variation of from 1.30 to 3.74 mgm. The column of averages shows that the vertical distribution is quite satisfactory. As in the Whittier soil, the highest average is found at a depth of 12 to 24 inches.

The basin at Arlington mulched with barley straw contains much less nitric nitrogen than the basins discussed above, and the vertical distribution is somewhat less satisfactory. The highest amount of nitrates are found in the upper 3 inches and the second highest at a depth of 36 to 48 inches, which, for this soil, is probably below the bulk of the feeding roots.

The basin at Riverside mulched with alfalfa hay is very low in nitrates, but the distribution is fairly uniform.

The basin in the Highgrove section does not contain large amounts of nitrates; but, as the supply is very well distributed, the amount is probably sufficient for the needs of the trees.

While the studies on the distribution of nitric nitrogen in basin-irrigated soils are too limited to warrant any definite conclusion at this time, it would seem that the distribution of nitric nitrogen in basin-irrigated soils is far more satisfactory than in furrow-irrigated soils. The substitution of a mulch for cultivation also permits the feeding roots to come near the surface, and, thus, the nitrates and other plant food in the surface layer can be more completely utilized than under the furrow system.

EFFECT OF RAINFALL ON THE DISTRIBUTION OF NITRATES IN CITRUS SOILS

The effect of rainfall on the distribution of nitric nitrogen during the season of 1914-15 is shown in figure 18. The rainfall from November 12, 1914, to January 23, 1915, amounted to 3.36 inches, but it fell in light showers over a period of nearly 10 weeks and seems to have had

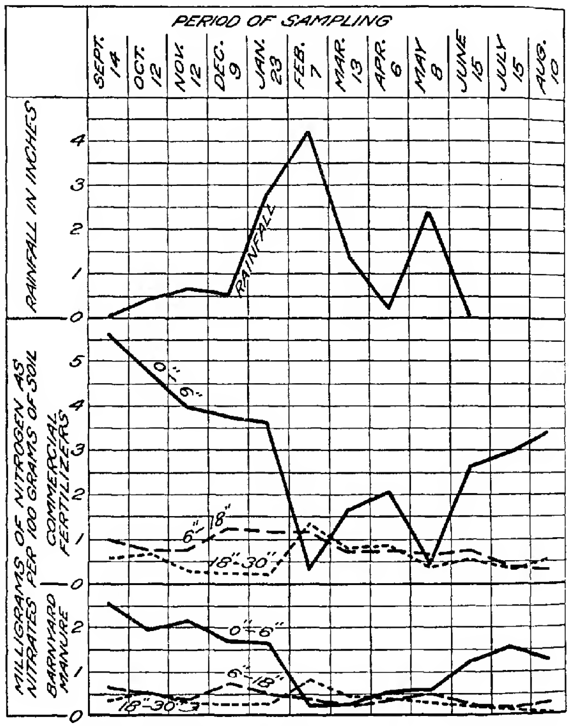

FIG. 18.—Diagram showing the effect of rainfall November 12, 1914, to July 15, 1915, on the distribution of nitrates in soils at Riverside, Cal.

little effect on the movement of nitrates in the soil. From January 23 to February 7 the rainfall amounted to 4.22 inches. The effect of the rainfall during this period on the distribution of nitrates is very marked. In the soils which had received commercial fertilizers the nitrates in the upper 6 inches fell from 3.62 to 0.31 mgm. There was no increase in nitrates at a depth of 6 to 18 inches; but at a depth of 18 to 30 inches

there was an increase from 0.23 to 1.37 mgm., indicating that a portion of the nitrates removed from the surface 6 inches was deposited at a depth of 18 to 30 inches. In the soils which have received barnyard manure the nitrates in the upper 6 inches of soil amounted to 1.65 mgm. on January 23, and on February 7 only 0.25 mgm. was found. During the same period there was an increase in nitrates at a depth of 18 to 30 inches from 0.30 to 0.85 mgm., thus confirming the results secured in the soils receiving commercial fertilizers.

There is a marked increase in nitrates in the upper 6 inches of the soils receiving commercial fertilizers from February 7 to April 6. This increase is due to the application of nitrogenous fertilizers from February 27 to March 1. The rainfall from February 27 to April 6 amounted to only 0.56 inch; and, as this quantity fell in light showers, the rainfall during this period could have had little or no influence on the distribution of the nitrates. It is interesting to note that, while there is a marked increase in nitrates in the upper 6 inches of soil of the plots receiving commercial fertilizers, there is little or no increase from 6 to 18 or from 18 to 30 inches in these soils. Very little increase is seen in the soils receiving barnyard manure, even in the upper 6 inches. As the manure was applied in February, it would seem that the nitrogen in manure becomes available very slowly in these soils.

From April 15 to 18 about 3 acre-inches of irrigation water were applied, and from April 20 to May 2 the rainfall amounted to 2.24 inches. The soil was well moistened by the irrigation; and, as the weather conditions during this period were such as to permit only slight loss from evaporation, the rainfall during this period was very effective in moving the nitric nitrogen out of the surface layers. On April 6 the average nitrate content of the upper 6 inches of the seven plots receiving commercial fertilizers amounted to 2.07 mgm. On May 8 the amount found was only 0.42 mgm., and there was also some reduction in the lower layers, indicating that the nitrates moved from the surface were carried downward to a considerable distance.

The nitrates in the manured soils were low during the spring, and the rainfall from April 20 to May 2 seems to have had little effect on the nitrates in these soils. However, it is quite possible that nitrification of the manures from April 6 to May 8 was sufficient to maintain the low nitrate content in these soils against the leaching effect of the rains.

It is observed that a very marked increase in nitrates has taken place from May 8 to June 15 in the upper 6 inches of soil in the plots receiving commercial fertilizers, but that the increase below the 6-inch layer is very slight and in some cases no increase is observed. The marked increase in the upper 6 inches of soil at this period is no doubt due to the second application of fertilizer which was added May 15.

There is also an increase in nitrates in the upper 6 inches of the manured soils, which indicates that the nitrification of the manure was now

taking place more rapidly than during the first two months after its application. There is a decrease in the nitrates from 6 to 30 inches in the manure plots, which is possibly due to the assimilation of the nitrogen by the trees.

Six sets of samples were taken from groves at Lordsburg on January 7, 1916. A second set of samples was taken on January 26. Each sample for analysis was made up of six borings, and the borings required for each set of samples were located as near each other as practicable. Between January 7 and January 26 there was a rainfall of 14.89 inches. The effect of the rainfall is shown in figure 19. Soil 1 contained only a small quantity of nitric nitrogen at the time the first set of samples was taken, but the amount contained was rather evenly distributed to a depth of 42 inches. On January 26 the nitrates in soil 1 had been reduced to about one-fourth of the amount present on January 7. The amount of nitrates found below a depth of 42 inches indicates that the rains between January 7 and 26 had carried the nitrates removed from the upper layers of soil below a depth of 96 inches.

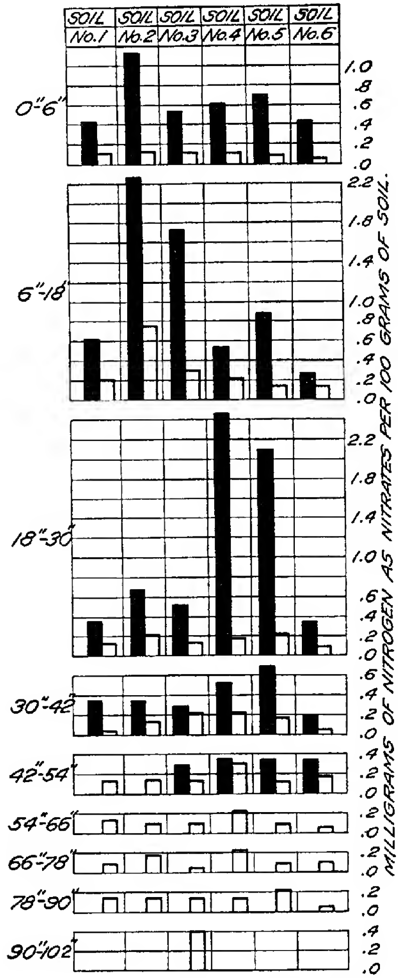

FIG. 19.—Diagram showing the effect of rainfall January 7 to January 26, 1916, on the distribution of nitrates in soils at Lordsburg, Cal. The black columns show the nitrate content of the soils on January 7 and the blank columns of January 26.

Soil 2 contained about 162 pounds of nitric nitrogen per acre on January 7 in the upper 3½ feet. After the heavy rains between January 7 and 26, the soil was found to contain only about 70 pounds to a depth of 90 inches. It would therefore seem that the loss of nitrogen in this soil from these rains was at least 100 pounds per acre.

Soil 3 is a heavy clay soil which contained a considerable quantity of nitrogen at a depth of 6 to 18 inches on January 7. About three-fourths of the nitrates contained in this soil seems to have been lost by leaching between January 7 and 26.

Soils 4 and 5 were taken from different parts of the same grove, and both were found to contain considerable quantities of nitrates on January 7. The loss in these soils must have amounted to well above 100 pounds per acre as a result of the rainfall from January 7 to 26.

Soil 6 contained only a little nitric nitrogen at the time the first set of samples was taken, but the amount found after the heavy rains is much smaller. The small amount of nitric nitrogen found from 66 to 90 inches indicated that the nitrates removed from the surface layers in these soils had been carried well beyond the reach of the roots and beyond the depth where capillary action might be a factor in returning them to the surface layers.

From September 30 to October 7, 1916, the rainfall at Riverside amounted to 1.80 inches. Immediately after these rains samples were taken from three soils at Riverside and one at Arlington. At least 75 per cent of the nitric nitrogen in the first foot of these soils was located in the upper 3 inches before the rains. The distribution of nitrates in the soils after the rains is shown in Table XXIX.

TABLE XXIX.—*Effect of rainfall from September 30 to October 6, 1916, on the distribution of nitrates in Citrus soils*

[Results expressed as milligrams of nitrogen per 100 gm. of soil]

Depth.	Plot A.							Plot H.						
	Boring No.							Boring No.						
	1	2	3	4	5	6	Average.	1	2	3	4	5	6	Average.
Inches.														
0-3	0.11	0.11	0.11	0.04	0.04	0.11	0.09	0.32	1.02	0.22	0.18	0.46	0.50	0.45
3-6	1.93	.67	1.02	1.65	1.16	2.07	1.42	15.10	7.39	1.30	1.90	4.38	13.20	7.21
6-9	4.87	6.55	1.93	2.35	3.19	1.72	3.43	6.20	4.03	.88	9.70	6.13	3.75	5.12
9-12	.60	2.00	.67	.32	.39	.11	.68	2.35	.60	.60	1.16	3.37	1.23	1.55
	Soil from Arlington, Cal.							Plot C.						
0-3	.42	.53	.39	.25	.39	.36	.39	.46	.39	.25	.29	.36	.25	.33
3-6	1.37	1.86	.53	.39	.95	.25	.89	4.66	3.02	1.79	.53	1.02	1.51	2.09
6-9	.53	.32	.22	.32	.39	.15	.32	4.52	4.73	2.42	2.00	1.30	1.44	2.74
9-12	.15	.25	.11	.11	.15	.04	.14	.67	.88	.99	.88	.60	.47	.75

Samples taken from plot A on October 7 show that the distribution of the nitrates has been materially changed by the 1.80 inches of rain. After the rain the largest amount of nitric nitrogen, as shown in Table XXIX, is found at a depth of 6 to 9 inches and the next largest at a depth of 3 to 6 inches.

The distribution of nitric nitrogen in soils C and H on October 7 also shows that the 1.8 inches between September 30 and October 7 caused a movement of the nitrates out of the upper 3 inches of soil into the second and third sections.

Samples taken from a clay soil at Arlington after the rain show the highest nitrate content at a depth of 3 to 6 inches, while the surface 3 inches contains but little more than the soil from 6 to 9 inches.

The rain between September 30 and October 7 fell on the soils just as they were being prepared for irrigation, and consequently the moisture content was low. In taking the samples for analysis it was observed that the rain had been absorbed by the upper 9 inches of soil. In studying the columns of averages in Table XXIX it is seen that the movement of nitrates was also within the upper 9 inches of soil, the nitrates being leached out of the upper 3 inches and deposited at a depth of 3 to 9 inches.

RELATION OF NITROGEN TO MOTTLE-LEAF

Mottle-leaf, as applied to Citrus plants, is frequently accompanied by marked reduction in quantity and quality of fruit, and in advanced stages the vigor of the tree is also much impaired. As the mottling of Citrus plants had become quite widely distributed the cause of mottling has received much attention from a number of investigators during recent years. Many causal agents have been suggested, but none of the theories advanced seems to offer an entirely satisfactory explanation of this disease.

The relation of available nitrogen to mottle-leaf has been discussed by Kellerman and Wright (6) and also by Lipman (7). The total nitrogen in a large number of Citrus groves showing various degrees of mottling has been reported upon by Briggs, Jensen, and McLane (1).

In the work reported in this paper much attention has been given to the formation and distribution of ammonia and nitrates, and their possible relation to mottling has been kept in mind. In the early part of the work it was shown that the ammonia content of the soils studied was apparently changed very little by the difference in soil treatment. The application of large quantities of nitrogenous fertilizers caused only a small increase in the ammonia, and the writer has not been able to secure any evidence that any relationship exists between the ammonia content of the soil and the character of the trees or fruit produced.

However, during the progress of the work it was observed that those plots which received larger applications of nitrogen in commercial fertilizers generally bore badly mottled trees. The trees which received no

nitrogen generally showed little mottling, as did the trees receiving barnyard manure, especially when the manure was combined with a cover crop. The data presented in figures 3 to 17 show that the highest accumulation of nitrates was found in plots A, C, G, H, and L, and also that the seasonal variation in nitrates is quite marked in these soils. A study of the degrees of mottling shows that the trees on these plots are more mottled than the trees on the other plots of the grove. In many other groves extreme mottling is frequently associated with high nitrate content, although some notable exceptions have been observed.

It is well known that the percentage of nitrogen in plant tissues varies with the available nitrogen content of the soils, and it would seem that if mottle-leaf is induced by the assimilation of excessive amounts of nitrogen an analysis of mottled leaves, if taken at the time of mottling, should show a higher nitrate content than healthy leaves of the same age from the same tree. On October 26, 1916, a quantity of healthy and mottled leaves was collected from seven individual trees on plots A, H, O, R, S, T, and V. The leaves selected were all formed during the late summer and were of as nearly the same age as it was possible to secure.

In order to obtain a representative sample of the two types of leaves, 100 gm. of clean leaves were selected from each tree. The percentage of moisture and nitrogen found in the leaves is shown in Table XXX. It is observed that the moisture content of the mottled leaves is invariably higher than in the healthy leaves. The nitrogen content of the mottled leaves is also higher except from trees in plots R and T, neither of which has received any nitrogenous fertilizer. However, it is observed that the nitrogen content of the leaves from trees on plots R and T is much below that found in leaves taken from trees on plots which have received nitrogenous fertilizers. It would therefore seem that the fertilization has increased the nitrogen content of the leaves. However, it is also seen that the healthy leaves from trees on the fertilized plots are much higher in nitrogen than the mottled leaves from the unfertilized plots.

TABLE XXX.—*Moisture and nitrogen content of healthy and mottled orange leaves*

Plot.	Moisture.		Nitrogen.	
	Healthy leaves.	Mottled leaves.	Healthy leaves.	Mottled leaves.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
A	61.62	66.56	2.69	3.41
H	60.86	66.37	2.92	3.93
O	60.58	66.67	2.91	3.25
R	62.10	63.57	1.99	1.99
S	62.67	68.08	2.89	3.34
T	60.10	63.71	2.00	2.00
V	60.86	63.52	3.06	3.40

It is well known that the addition of nitrogenous fertilizers to Citrus soils may be influential in bringing about important changes in the chemical composition of the soils, and it is possible that these changes, especially in the absence of organic matter, may be responsible, in some measure at least, for the apparent correlation between high nitrate content and mottling.

It must also be recognized that high nitrate content of the surface soil is frequently associated with unfavorable soil conditions. In a large percentage of badly mottled groves a rather impervious plowsole develops just below the cultivated zone. The plowsole is a serious obstacle to irrigation and frequently results in an inadequate soil moistening and a very uneven and unsatisfactory distribution of the nitrates and other soluble plant food. It would seem that the extremely variable supply of plant food and soil moisture may be an important factor in mottling. Indeed, Smith and Smith (10), in 1911, expressed the view that the most prevalent type of mottling is due to such conditions.

SUMMARY

(1) Semiarid soils frequently fail to nitrify dried blood when added in 1 per cent quantities, but invariably nitrify blood when added in amounts not greater than are ordinarily applied under the field conditions.

(2) The addition of dried blood to semiarid soils in 1 per cent quantities frequently caused large amounts of ammonia to accumulate in the soil. The addition of dried blood or other nitrogenous substances applied as fertilizers caused no marked increase in the ammonia content of the soils.

(3) When 1 per cent of dried blood is added to semiarid soils, as much as 50 per cent of the nitrogen added may be lost during an incubation period of six weeks. As the soils frequently give off a strong ammoniacal odor, it is believed that this loss is due, in a large measure at least, to the volatilization of ammonia.

(4) Ammonification or nitrification studies on semiarid soils in which 1 per cent of dried blood is added are of questionable value and may lead to erroneous conclusions.

(5) Green manures, especially the legume varieties, nitrify very rapidly. As much as 50 per cent of the nitrogen contained in green plant tissues may be converted into nitrates in 30 days.

(6) Green manures furnish a valuable source of energy for the nonsymbiotic nitrogen-fixing organisms.

(7) The furrow system of irrigation frequently causes a very unsatisfactory distribution of the soil nitrates. In many Citrus groves more than two-thirds of the nitric nitrogen in the upper 4 feet of soil is found in the surface 6 inches, in which, because of the frequent cultivation, few feeding roots are found.

(8) The furrow system of irrigation frequently causes the formation of niter spots. Surface scrapings from these spots in heavily fertilized groves may contain as much as 1 per cent of nitrogen as nitrates.

(9) The brown color which characterizes the niter spots is probably due to a number of factors, but it is believed that the deliquescent character of the calcium nitrate is important in this regard.

(10) Where the furrow system of irrigation is employed, the fertilizing materials should be plowed down somewhat deeper than the land is cultivated. The feeding roots will then have an opportunity to assimilate the food as it is rendered available, whereas, if it is formed within the cultivated zone, the irrigation will tend to carry it farther away from the roots.

(11) Much nitric nitrogen is lost from Citrus lands by leaching. The most effective means of preventing this loss is by growing a winter cover crop.

(12) Basin irrigation or overhead irrigation gives a more satisfactory distribution of soil nitrates than the furrow system.

(13) The basin system of irrigation seems to give greatest promise when combined with a mulching system. However, the rapidity with which organic materials rich in nitrogen decay would seem to make it inadvisable to maintain a constant mulch with these materials, as the nitrates produced will probably be far in excess of the needs of the tree, and much loss will result.

(14) Mottled orange leaves have a higher moisture content than healthy leaves of the same age from the same tree. The nitrogen content of mottled leaves is also generally higher than healthy leaves.

(15) Extreme mottling is frequently associated with a high nitrate content, but the correlation is by no means an invariable one.

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